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Measurement of the Spatial Dependence of Temperature and Gas and Soot Concentrations Within Large Open Hydrocarbon Fuel Fires

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INTRODUCTION

In March 1979, The White Sands Test Facility (WSTF) was requested by the Ames Research Center to perform a series of large-scale JP-4 pool fire tests. These experiments were designed by the Ames Research Center and were funded by the Langley Research Center Graphite Fibers Risk Analysis Office, which is interested in developing analytical predictions of fiber dispersion. These experiments were performed to provide data which would be used in the modification of existing mathematical models of large fires and soot plumes. This report contains a description of the experimental technique and a tabulation of the resulting data.

BACKGROUND

The high-strength and low-weight properties of graphite composites indicate that extensive use of such materials in aircraft is desirable. The graphite fibers used in such composite materials are lightweight and have a high electrical conductivity. These properties present a potential hazard to electrical equipment if such fibers inadvertently contaminate susceptible components. A mechanism for a hazardous contamination exists if the material is burned in such a way that the small low-density graphite fibers are lifted by the fire plume and subjected to atmospheric distribution processes. The potential for this situation in aircraft accidents and in waste disposal by incineration indicates the need to assess the risks involved in commercial use of graphite composites.

The mathematical prediction of the dissemination of graphite fibers in large-scale fires is dependent on the uncertainties in modeling the characteristics of large fires. A review of the best available model of the characteristics of large fires by the Ames Research Center identified the uncertainties and the type and location of measurements required to reduce these uncertainties. Temperature, gas species concentration, and soot concentration measurements were made throughout the interior of 7.5- and 15-meter-diameter JP-4 fuel fires and are described in this report.

OBJECTIVES

The primary objective of this effort was to determine the spatial dependence of temperature, fuel, air and soot in 7.5- and 15-meter-diameter JP-4 fuel fires. Radiant and combustion heat flux, combustion products and local meteorology measurements were also made. Photographic coverage of each test included 24- and 200-frame-per-second movies and time-correlated still photographs of the soot plume and residual cloud. These measurements were made to document the general characteristics of each test.

APPARATUS

The test system (fig. 1) consisted of a concrete pad for the fuel pond, a tower and support structure that facilitated placing instruments in the fire, and an instrumentation and control system that provided for temperature data acquisition, chemistry sampler control, and fuel ignition controls.

A 0.1-meter-thick steel-reinforced concrete pad that was flat and level to within 6 millimeters provided the surface for the fuel pond. Peripheral containment of the fuel was accomplished with a 0.1-meter-high concrete curb placed at the appropriate perimeter. The pool was designed to contain approximately 1500 and 5600 liters of fuel for the 7.5- and 15-meter-diameter fires. The area around the pool was cleared to a radius of 75 meters.

Instrumentation was suspended in the fire at heights of 21.3, 11.4, 5.7, 2.9, and 1.4 meters on five Y-shaped instrumentation support structures. These structures were fabricated of 3-millimeter-thick, 50- by 152-millimeter rectangular tubing. The primary leg of a support structure was 8.2 meters long with a 1.8-meter extension that allowed temperature measurements to be made up to 10 meters from the center of the pond. The remaining two legs of the structure were each 3.8 meters long and were instrumented to determine the symmetry of the fire. The upper two levels of the instrumentation support structure were suspended on catenaries of 9-millimeter steel cable, each supported by three 27.4-meter towers. The structures were raised and lowered with 6-millimeter steel cable rigged to manual winches. The three towers each consisted of a 0.76-meter-diameter, 18.3-meter-high steel pipe with an additional 9.1 meters of 0.46-meter-diameter pipe spliced to the top. The lower instrumentation support structures were supported at the ends with 0.15-meter-diameter aluminum pipe. The instrumentation support structures were insulated with two 25-millimeter layers of high-temperature insulation reinforced with chicken wire. The 27.4-meter towers were open at the top and filled with water to provide an additional heat sink.

The instrumentation consisted of up to 52 thermocouples, 24 chemistry samplers, a meteorological balloon, 3 windspeed and direction indicators, 6 16-millimeter movie cameras, 2 calorimeters, 2 radiometers, and a data acquisition and chemistry sampler control system (fig. 2). The dc power used to operate the chemistry samplers and the manually activated igniter circuits was provided by three automobile batteries wired in series.

The thermocouples used to make the fire temperature measurements were fabricated of 24 AWG chromel-alumel wire. A 0.46-meter ceramic tube was used to protect and strengthen the thermocouple so that an extension from the structure of at least 0.3 meters could be achieved. Accuracy of the temperature measurements was limited to $\pm$ 14 K because of the extensive cable distance to the data acquisition system.

The chemistry samplers (fig. 3) consisted of an appropriately-sized ceramic probe, a solenoid-operated sampling valve, a gas temperature quencher equipped with a ceramic soot filter, a capillary tube, a solenoid-operated isolation valve, a 3.1-liter stainless steel bottle, and a manual servicing valve. The

solenoid valves were operated in parallel and were redundant to insure the integrity of the gas sample. The ceramic probe provided thermal isolation for the inlet valve. Ceramic probes of various diameters were used to obtain an isokinetic sample of particulate for the predicted gas velocity at the sample location. The quencher was experimentally shown to have the capability to cool up to 6 liters of 1600-K inlet gas to less than 360 K. The capillary tube was sized to obtain an isokinetic velocity through the sampler over a 30-second period of sampling. The sampling apparatus was insulated in a pod of three 25-millimeter layers of high-temperature insulation reinforced with chicken wire (fig. 4). A strong back and sampler support bracket provided mounting to the instrumentation support structure at two points that provided horizontal and vertical stability in the turbulent environment of the fire. The ceramic sampling probe length was maintained at a minimum of 0.3 meter to minimize sampling interference from gaseous flow patterns caused by the structure. The components of the fire were separated into three groups by the samplers; soot was trapped in the ceramic filter, water and condensable hydrocarbons were condensed in the quencher and capillary tube, and gaseous compounds were isolated in the stainless steel bottle.

The meteorological balloon and the wind direction and speed indicators were used to determine the pretest and test atmospheric conditions. The balloon was equipped to determine the barometric pressure ($\pm$ 1 millimeter), temperature ($\pm$ 0.1 K), relative humidity ($\pm$ 1 percent), wind direction ($\pm$ 5°), and windspeed ($\pm$ 0.5 m/s) at 150-meter increments of altitude. Windspeed ($\pm$ 0.5 m/s) and wind direction ($\pm$ 5°) indicators were also mounted at 7.5-, 15-, and 22.5-meter heights on a pole approximately 215 meters from the fuel pond.

Photographic coverage of each test was obtained with 16-millimeter movie cameras at three locations (fig. 5). Photographs of the soot plume and the cloud were taken with a 40-millimeter camera approximately 5 kilometers from the test site. Film speed at each location was 24 frames per second for the test duration. High-speed (200 frames per second) motion pictures of 60 seconds of each fire were obtained at one location.

PROCEDURES

The procedures used for the seven pool fire tests consisted of a pretest setup, a test procedure, and an analytical procedure. The pretest procedure was dominated by the location, verification, and calibration of the instruments. The test procedure consisted of the operation of the test system to make the measurements. The analytical procedure consisted of the gas analysis and data reduction.

Pretest Procedure

Thermocouples were mounted on all three legs of the support structure as identified in the data table for each test. The primary instrumentation leg was designated as leg A, the secondary legs were designated as B and C (fig. 5). The thermocouples were mounted by securing the interface connector to the

underside of the insulation-reinforcing chicken wire. The measurement bead of the thermocouple was oriented below the support structure and extended at least 0.3 meter beyond the insulation. Verification of the correct measurement location to each data channel was accomplished by heating the thermocouple with a soldering iron and obtaining an increase in temperature at the data system. Calibration of the thermocouples was accomplished by heating each located thermocouple with an oil bath at approximately 400 K ($\pm$ 5 K) and observing the correct temperature indication on the data system. After verification and calibration, the data acquisition system was activated to obtain the ambient temperature on all the thermocouples each second for 300 seconds. The resulting noise and temperature drift was verified to be less than $\pm$ 5 K.

Preparation and mounting of the chemistry samplers consisted of cleaning, assembling, leak-testing, insulating, and mounting. Each sampler was disassembled and each component was cleaned to the WSTF preclean level. This consisted of soaking in a 320-K Oakite bath, a distilled water rinse, an isopropyl alcohol rinse, and a Freon TF rinse. The sample bottle, the isolation solenoid valve, and the manual valve were then assembled and pressure leak checked by pressurizing the bottle to 4400 pascals with nitrogen and immersing the assembly in Freon. After remedying any gross leaks, the sampler was completely assembled and evacuated to less than 0.14 pascal. The vacuum level was verified to be less than 0.6 pascal 24 hours after evacuation. The sampler was then insulated in the pod and a final vacuum level check was performed to insure that the pressure was below 3 pascals. Typically, the final vacuum level was less than 1.5 pascals in the final pretest configuration. The sampling pods were mounted below the instrumentation structure in the desired locations. The appropriately sized ceramic sampling nozzle was attached to each sampling pod on the test date. Termination of the sampling pod valve controls was verified with a continuity check. Insulating the instrumentation support structures completed the final installation of the chemistry samplers.

Two water-cooled calorimeters were installed at the center of the pool. Both were oriented horizontally so that the measurement surface faced the center of the area between the secondary legs of the instrumentation support structure. One calorimeter was placed at a height of 1.4 meters above the pool and the other was placed at 2.8 meters above the pool. Two water-cooled radiometers were installed 22.5 meters from the center of the pool bisecting the angle formed by the primary instrumentation leg and the respective secondary instrumentation leg. The radiometers were mounted at a height of 0.9 meter and were focused on the center of the 5.7-meter-high instrumentation support structure. Motion picture cameras were mounted at three locations. Two stations were located 91 meters from the center of the pool bisecting the angles formed by the A and C and the A and B instrumentation support legs. The third station was located 305 meters from the pool at the angle bisecting the angle formed by the A and C instrumentation support legs.

Test Procedure

1. A favorable weather forecast was obtained.

2. Nichrome igniters were installed at three locations in the fuel pond and were loaded with solid alcohol pellets.

3. Instrumentation integrity was verified on a channel-by-channel basis.

4. The fuel fill pipe was installed and the fuel truck was grounded.

5. Nylon ropes with weights attached to one end were attached to each end of the upper support structures so the height of the structures when raised could be verified at 21.3 and 11.4 meters $\pm$ 0.3 meter.

6. The 21.3- and the 11.4-meter-high instrumentation support structures were raised after clearing the area of personnel.

7. The fuel pond was filled to a depth of 31 $\pm$ 3 millimeters of JP-4 fuel.

8. The power to the chemistry sampler and the igniter circuits was connected.

9. The water valves to the water-cooled instrumentation were opened.

10. Upon favorable indications of calm wind conditions (less than 0.2 m/s), a weather balloon was released and atmospheric conditions were measured and recorded.

11. The motion picture cameras and the remote still photographs were initiated.

12. The primary igniter circuit was activated.

13. The data acquisition system was activated upon visual verification of ignition.

14. Chemistry samplers were opened for 30 seconds at a predetermined time into the fire or upon test-director instruction based on visual verification of vertical fire symmetry.

15. Data acquisition and motion picture cameras were deactivated upon termination of the fire.

16. Still photographs of the smoke cloud were taken every minute until the cloud dissipated.

17. After the test system returned to near-ambient conditions, the upper instrumentation support structures were returned to ground level.

18. The chemistry sampler and the igniter circuit power were deactivated.

19. The chemistry samplers were removed from the structure, identified as to location, and transported to the chemistry laboratory for removal of insulation and analysis.

20. The cameras were serviced and the film was submitted for processing.

21. All data acquisition channels were functionally checked and anomalies were recorded.

Analytical Procedure

The chemistry samplers were removed from the insulation pod and allowed to cool to room temperature. A sampler was then attached to the gas chromatograph system, and the temperature and pressure of the sampler were measured and recorded. The percent volume content of hydrogen, argon, oxygen, methane, and carbon monoxide were determined by gas chromatography using a 3.6-meter-long, 4.75-millimeter-diameter, 60- to 80-mesh Mole Sieve 5A stainless steel column with a 25-cc/min helium carrier gas. Two methods were used to determine the gaseous constituents in each sampler, one isothermal and one temperature-programed. The isothermal method at 373 K for 16 minutes yielded the reported values for hydrogen, methane, and carbon monoxide as well as for argon and oxygen combined. The temperature program was 248 K for 12 minutes, followed by a 30-K/min rate of increase to 373 K, which was then maintained for 20 minutes. The programed temperature method was used to determine argon and oxygen individually and to cross-check the values previously obtained for hydrogen, methane, and carbon monoxide. Nitrogen was also determined by both methods and was used as a system consistency reference. A third determination was made using a 2.4-meter-long, 3-millimeter-diameter, 50- to 80-mesh, Porapak Q stainless steel column with a 25-cc/min helium carrier gas. The column temperature was programed to maintain 323 K for 7 minutes followed by a 10-K/min increase to 448 K, which was maintained for an additional 70 minutes. This determination provided the concentration of methane, carbon dioxide, ethylene and acetylene, and other hydrocarbons up to C-9. The methane value provided a check on the value obtained with the Mole Sieve determination and the other constituents were reported from this analysis. Although water was eluted from the Porapak Q column, the data were not reproducible and did not appear to be useful. The reported value for nitrogen was determined by difference from the total volume percent of the measured constituents. Calibration of the thermal conductivity detector was done with gravimetric standards prepared by Scott Environmental Technology, Inc. All hydrocarbons except methane, ethylene, and acetylene were measured as propane.

Identification of individual hydrocarbons was done using a gas chromatograph interfaced with a Finnigan Model 1015D quadripole mass spectrometer equipped with a computer analysis system. Separation of the sample was with a 1.5-millimeter-diameter Porapak R column with the quantitative determinations based on a propane standard furnished by the National Bureau of Standards. Identification was made by comparison to reference mass spectral compilations.

The sampler probe, the quencher assembly, and the associated tubing were separated from the gas sampler, disassembled, and rinsed with acetone. The acetone rinse was filtered through the soot collection thimble and placed in a Soxhlett extraction assembly. The thimble was extracted with acetone rinses until at least five cycles had been completed. The amount of condensed hydrocarbons and water in the acetone was then determined with liquid chromatography using a silica column, an acetone carrier, and a refractive index detector. The value reported for condensed hydrocarbons was measured as JP-4. The soot thimble was then dried to a stable weight at 363 K in a vacuum oven and ignited in a muffle furnace at 773 K. Soot content was determined by weight loss upon ignition. An alternate procedure of measuring the soot content consisted of heating a dried thimble in a combustion train and measuring the carbon/hydrogen ratio as well as the weight loss upon combustion.

The data obtained from the chemistry analysis were reduced to component weights and mass fractions. The gaseous component weights were determined using the ideal gas law with the container volume, the final temperature and the final pressure as knowns, and the total weight of the gaseous components calculated on a water-free basis. The gas mass fractions were then determined based on the total weight of the gaseous components existing at the sample bottle inlet at the test conditions, which includes the calculated weight of water based on the measured values for carbon monoxide and carbon dioxide and the measured weights of unburned hydrocarbons as well as the components measured in the gaseous state. The water formed by combustion was calculated in two ways. One water calculation was made by difference, balancing all of the oxygen containing species. Another water calculation considered the combustion process and the amount of carbon monoxide and carbon dioxide produced. A simplified representation for JP-4 of C_nH_{2n} indicates that the moles and volume percent of carbon monoxide and carbon dioxide are related to water as follows:

$$C_n\ H_{2n} + 3/2\ n\ O_2 \quad n\ CO_2 + n\ H_2O$$

$$C_n\ H_{2n} + n\ O_2 \quad n\ CO + n\ H_2O$$

Thus the volume percent of water produced by combustion is equal to the sum of the volume percents of the carbon monoxide and carbon dioxide. The total mass fraction was determined by adding the weight of the soot and correcting the gas mass fraction values with the soot value included.

Thermocouple values were reduced by curve-fitting to an eighth-degree polynomial after adjusting the value to account for the ambient temperature at the multiplexer interface. Temperature channel anomalies were determined by performing correlation tests to nearby measurement locations and by manual comparison to surrounding measurement trends. Data were deleted only where there was a lack of correlation to all surrounding measurements.

RESULTS

A summary of the seven JP-4 pool fire tests is tabulated in table I. The first test was a partially instrumented 7.5-meter-diameter fire which was designed to functionally test the insulation and instrumentation system and was designated as the pretest fire. Four additional tests were conducted with a 7.5-meter-diameter pool; however, test 1 was performed during what proved to be excessive winds for this experiment. The chemistry samples were not taken during test 1 because of the instability of the fire. Test 2 was successfully completed on the day following test 1; however, the wind velocity of 0.4 m/s caused the fire to lean excessively. During test 3, no chemistry samples were taken. On the following day, test 4 was conducted and a data acquisition failure resulted in the loss of temperature data. However, tests 3 and 4 were performed under very similar conditions and will be treated as one test for data comparison purposes. The last two tests, test 5 and test 6, were fully instrumented 15-meter-diameter fires and all the data was successfully obtained.

A complete tabulation and compilation of the data obtained during each test is listed in the White Sands Test Facility report number TR-259-001, "Measurement of the Spatial Dependence of Temperature and Gas and Soot Concentrations Within Large Open Hydrocarbon Fuel Fires." This report includes the temperature, analytical, and meteorological data and the photographs obtained of the smoke plume development and dispersion for each test. Also included are the motion picture setup specifications for each test.

Experimentally measured water values were not consistent with combustion processes. In some cases no water was found and in others very large amounts were measured even though some of the high values were actually measured outside the observed fire area. During the test program sources of evaporating water were identified in addition to that formed by combustion. Low water values possibly occurred when the water was produced in concentrations below the dew point at ambient temperature. The experimental data on water are included in the percent by volume tables, however, only the water value computed from carbon monoxide and carbon dioxide were used to calculate mass fractions.

The average temperature (for a stable portion of the test), the measured oxygen, carbon monoxide, carbon dioxide, gaseous fuel, and soot concentration profiles for each measurement height for test 2 are shown in figures 6 through 11. The average temperatures for a stable portion of the fire are tabulated in table II. The chemistry data obtained during the test are given in table VI. The portion of the fire from which the average temperatures were obtained was from 10 to 40 seconds into the fire. The chemistry samplers were activated at 2 minutes into the fire and continued sampling for 30 seconds. All radial distances are given from the center of the pond and are not adjusted to consider wind effects.

The average temperature profiles taken during test 3 (from 14 to 44 seconds into the test) are plotted with the combustion chemistry concentration (taken during test 4) profiles obtained from 30 to 120 seconds into the test (figs. 12 to 17). The average temperatures obtained for the stable portion of test 3 are given in table III. The chemistry data obtained during test 4 are given in table VII.

The average temperature profiles obtained during test 5 from 40 to 81 seconds into the fire are plotted with the combustion chemistry concentration profiles obtained from 30 to 60 seconds into the test (figs. 18 to 23). The average temperatures obtained for the stable portion of the test are listed in table IV. The chemistry data obtained during the test are given in table VIII.

The average temperature profiles taken during test 6 from 80 to 129 seconds into the fire are plotted with the combustion chemistry concentration profiles obtained from 40 to 70 seconds into the test (figs. 24 to 29). The average temperatures otained for the stable portion of the test are given in table V. The chemistry data obtained during the test are given in table IX.

CONCLUDING REMARKS AND RECOMMENDATIONS

A measure of the spatial dependence of temperature and combustion chemistry in 7.5- and 15-meter JP-4 pool fires was attained during this program. Preliminary modifications to an analytical model of such fires have begun as indicated in a preliminary report, "Improvement of a Mathematical Model of a Large Open Fire," by Harsha, Bragg, and Edelman issued to the NASA Ames Research Center in September 1979 on Contract NAS2-10327. However, further evaluation of the data is required to determine whether scaling effects can be adequately deduced from the data obtained during these tests. As model evaluation and correlation with these data continue, the need for larger and more stable tests could be indicated.

TABLE I

TEST SUMMARY

Test	Pool Size (±0.2 m)	Fuel Depth (±3 mm)	Fire Duration (sec)	Maximum Evaporation Rate (mm/sec)	Minimum Evaporation Rate (mm/sec)	Wind Velocity (m/sec)	Fuel Quantity (liters)	Temperature Data	Chemistry Data
Pretest	7.5	32	309	6.14	4.92	1.3	1450	Yes	Yes
Test 1	7.5	32	260	7.31	7.11	0.89	1450	Yes	No
Test 2	7.5	35	214	9.77	8.00	0.44	1600	Yes	Yes
Test 3	7.5	38	267	8.55	5.76	0.22	1750	Yes	No
Test 4	7.5	38	N/A	N/A	N/A	0.22	7000	No	Yes
Test 5	15	38	330	6.90	5.76	0.08	7000	Yes	Yes
Test 6	15	32	214	8.89	7.11	0.08	5800	Yes	Yes

TABLE II
TEST 2
AVERAGE TEMPERATURE DATA
7.5-METER-DIAMETER JP-4 POOL FIRE
AVERAGE FROM 10 TO 40 SECONDS INTO THE FIRE

Height (meters)	Distance From Center (meters) Temperature (deg K)								
.7	0.0A	.7A	1.4A	1.8A	2.1A	2.5A	2.9A	3.4A	
	1213	1201	1220	1116	1100	1070	1015	738	
1.4	0.0A	.5A	.9A	1.3A	1.6A	2.0A	2.5A	3.4A	
	1019	1364	1341	1297	1280	1195	999	914	
2.9	.6A	1.2A	1.8A	2.4A	.6C	1.8C			
	1289	1410	1215	1027	679	644			
5.7	0.0A	.6A	1.2A	2.1A	3.2A	4.3A			
	710	930	1232	1222	1075	819			
11.4	0.0A	.9A	1.8A	3.4A	5.2A	.9B	1.8B	.9C	1.8C
	388	428	589	817	837	333	323	338	348
21.3	0.0A	1.2A	2.4A	3.7A					
	367	350	465	394					

TABLE III
TEST 3
AVERAGE TEMPERATURE DATA
7.5-METER-DIAMETER JP-4 POOL FIRE
AVERAGE FROM 14 TO 44 SECONDS INTO THE FIRE

Height (meters)	Distance From Center (meters) Temperature (deg K)										
.7	0.0A	.7A	1.4A	1.8A	2.1A	2.5A	2.9A	3.4A	4.0A		
	1016	977	1095	1129	1164	1091	831	569	443		
1.4	0.0A	.5A	.9A	1.3A	1.6A	2.0A	2.5A	3.4A	4.0A		
	1192	1234	1262	1256	1293	1271	969	551	405		
2.9	.6A	1.2A	1.8A	2.4A	3.0A	3.7A	4.3A	1.2B	1.8B	1.2C	1.8C
	1352	1374	1244	1151	786	511	397	993	615	1361	995
5.7	0.0A	.6A	1.2A	2.1A	3.2A	4.3A	5.5A	.6B	1.8B	.6C	1.8C
	1444	1389	1363	1042	701	397	314	1245	574	1441	1043
11.4	0.0A	.9A	1.8A	3.4A	5.2A						
	1237	1155	1189	821	402						
21.3	0.0A	2.4A	4.9A	7.3A							
	749	575	431	327							

TABLE IV
TEST 5
AVERAGE TEMPERATURE DATA
15-METER-DIAMETER JP-4 POOL FIRE
AVERAGE FROM 40 TO 81 SECONDS INTO THE FIRE

Height (meters)	Distance From Center (meters) Temperature (deg K)											
.7	0.0A	2.4A										
	885	1030										
1.4	0.0A	1.8A	3.7A	4.7A	5.6A	6.3A	7.1A	7.9A	8.8A			
	936	1167	1191	880	636	608	693	416	319			
2.9	-.9A	-2.1A	0.0A	1.8A	3.4A	4.0A	4.6A	5.2A	5.8A	6.4A	7.3A	8.5A
	1046	1195	1068	1375	1057	754	649	581	417	423	381	318
5.7	0.0A	.9A	1.5A	2.1A	2.7A	3.4A	4.0A	4.6A	5.5A	7.3A	3.7B	3.7C
	1304	1376	1362	1118	918	544	622	457	476	391	767	917
11.4	0.0A	1.5A	3.0A	4.9A	7.3A	10.1A	1.8B	3.7B	1.8C	3.7C		
	1477	1489	1143	642	364	340	1129	969	1275	701		
21.3	0.0A	2.4A	5.2A	7.9A	11.0A							
	1411	1037	550	364	326							

TABLE V
TEST 6
AVERAGE TEMPERATURE DATA
15-METER-DIAMETER JP-4 POOL FIRE
AVERAGE FROM 80 TO 129 SECONDS INTO THE FIRE

Height (meters)	Distance From Center (meters) Temperature (deg K)											
.7	0.0A	2.4A										
	874	939										
1.4	0.0A	.9A	1.8A	2.7A	3.7A	4.7A	5.8A	7.0A	8.1A			
	943	964	1078	1265	1307	950	721	574	450			
2.9	-.9A	-2.1A	0.0A	1.2A	1.5A	2.2A	3.0A	3.8A	4.6A	5.5A	6.4A	7.3A
	1083	1351	1053	1165	1284	1408	1324	1138	856	627	468	440
5.7	0.0A	.9A	1.5A	2.1A	2.7A	3.4A	4.0A	4.6A	5.5A	7.3A	3.7B	3.7C
	1295	1383	1416	1370	1289	1110	793	601	504	405	562	1019
11.4	0.0A	1.5A	3.0A	4.9A	7.3A	9.1A	1.8B	3.7B	1.8C	3.7C		
	1419	1496	1324	824	438	369	952	537	1306	853		
21.3	0.0A	2.4A	5.2A	7.9A	11.0A							
	1455	1234	658	405	356							

TABLE VI
TEST 2
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 120 TO 150 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water (a)	Water (b)	Water (c)
2.9	0.0	19.1	.0	1.1	1.1	1.5	.0
2.9	1.4	18.2	.0	1.7	1.7	2.1	.0
2.9	1.4	17.6	.1	2.2	2.2	2.0	.0
2.9	2.7	20.4	.0	.3	.3	.5	.0
5.7	0.0	20.2	.0	.1	.1	1.7	.0
5.7	0.0	21.1	.0	.1	.1	.0	.0
5.7	2.1	20.6	.0	.1	.1	.8	.0
5.7	2.1	20.5	.0	.1	.1	1.2	.0
11.4	0.0	20.3	.0	.0	.0	1.6	.0
11.4	3.4	21.4	.0	.0	.0	.0	.0
21.3	0.0	21.2	.0	.0	.0	.0	.0
21.3	3.4	20.8	.0	.0	.0	.3	.0

(a) Water calculation based on carbon monoxide and carbon dioxide.
(b) Water calculation based on oxygen.
(c) Water calculation based on measured mass of water.

TABLE VI CONTINUED
TEST 2
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 120 TO 150 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Hydrogen	Argon	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen
2.9	0.0	.0	.9	.0	.0	.0	77.8
2.9	1.4	.0	.9	.0	.0	.0	77.6
2.9	1.4	.0	.9	.0	.0	.0	77.1
2.9	2.7	.0	.9	.0	.0	.0	78.0
5.7	0.0	.0	.9	.0	.0	.0	78.7
5.7	0.0	.0	.9	.0	.0	.0	77.8
5.7	2.1	.0	.9	.0	.0	.0	78.3
5.7	2.1	.0	.9	.0	.0	.0	78.5
11.4	0.0	.0	.9	.0	.0	.0	78.7
11.4	3.4	.0	.9	.0	.0	.0	77.6
21.3	0.0	.0	.9	.0	.0	.0	77.8
21.3	3.4	.0	.9	.0	.0	.0	78.2

TABLE VI CONTINUED
TEST 2
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 120 TO 150 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
2.9	0.0	.211	.000	.016	.007	.000	.013
2.9	1.4	.200	.000	.025	.010	.000	.013
2.9	1.4	.194	.001	.033	.014	.000	.013
2.9	2.7	.224	.000	.005	.002	.000	.013
5.7	0.0	.224	.000	.001	.001	.000	.012
5.7	0.0	.233	.000	.001	.001	.000	.013
5.7	2.1	.228	.000	.001	.000	.000	.012
5.7	2.1	.226	.000	.001	.000	.000	.012
11.4	0.0	.225	.000	.001	.000	.000	.012
11.4	3.4	.236	.000	.001	.000	.000	.013
21.3	0.0	.234	.000	.001	.000	.000	.013
21.3	3.4	.230	.000	.001	.000	.000	.013

TABLE VI CONTINUED
TEST 2
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 120 TO 150 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen	Unburned Fuel
2.9	0.0	.000	.000	.000	.750	.003
2.9	1.4	.000	.000	.000	.749	.003
2.9	1.4	.000	.000	.000	.746	.000
2.9	2.7	.000	.000	.000	.749	.008
5.7	0.0	.000	.000	.000	.762	.000
5.7	0.0	.000	.000	.000	.752	.000
5.7	2.1	.000	.000	.000	.758	.000
5.7	2.1	.000	.000	.000	.760	.000
11.4	0.0	.000	.000	.000	.762	.000
11.4	3.4	.000	.000	.000	.750	.000
21.3	0.0	.000	.000	.000	.752	.000
21.3	3.4	.000	.000	.000	.756	.000

TABLE VI CONTINUED
TEST 2
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 120 TO 150 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
2.9	0.0	.211	.000	.016	.007	.000	.012
2.9	1.4	.200	.000	.025	.010	.000	.013
2.9	1.4	.194	.001	.033	.014	.000	.013
2.9	2.7	.224	.000	.005	.002	.000	.013
5.7	0.0	.224	.000	.001	.001	.000	.012
5.7	0.0	.233	.000	.001	.001	.000	.013
5.7	2.1	.228	.000	.001	.000	.000	.012
5.7	2.1	.226	.000	.001	.000	.000	.012
11.4	0.0	.225	.000	.001	.000	.000	.012
11.4	3.4	.236	.000	.001	.000	.000	.013
21.3	0.0	.234	.000	.001	.000	.000	.013
21.3	3.4	.230	.000	.001	.000	.000	.013

TABLE VI CONTINUED
TEST 2
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 120 TO 150 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen	Unburned Fuel	Soot
2.9	0.0	.000	.000	.000	.750	.003	.001
2.9	1.4	.000	.000	.000	.748	.003	.001
2.9	1.4	.000	.000	.000	.745	.000	.002
2.9	2.7	.000	.000	.000	.749	.008	.000
5.7	0.0	.000	.000	.000	.761	.000	.000
5.7	0.0	.000	.000	.000	.751	.000	.001
5.7	2.1	.000	.000	.000	.758	.000	.000
5.7	2.1	.000	.000	.000	.759	.000	.000
11.4	0.0	.000	.000	.000	.762	.000	.000
11.4	3.4	.000	.000	.000	.750	.000	.000
21.3	0.0	.000	.000	.000	.752	.000	.000
21.3	3.4	.000	.000	.000	.756	.000	.000

TABLE VII
TEST 4
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 120 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water (a)	Water (b)	Water (c)
.7	0.0	2.0	2.5	4.9	7.4	8.7	26.3
1.4	0.0	4.7	2.1	6.0	8.1	10.4	12.1
1.4	0.0	2.1	2.6	7.2	9.8	11.5	28.3
1.4	.5	1.4	2.9	6.1	9.0	11.3	8.1
1.4	2.0	9.8	.9	5.5	6.4	8.3	16.1
1.4	2.7	15.5	.2	3.0	3.2	4.2	12.7
1.4	3.7	17.5	.1	1.7	1.8	3.2	7.6
2.9	0.0	3.0	2.4	7.4	9.8	11.8	15.1
2.9	0.0	5.8	1.7	6.3	8.0	10.2	27.1
2.9	1.4	12.1	.6	4.3	4.9	7.1	17.7
2.9	1.4	10.9	.5	5.4	5.9	7.3	30.0
2.9	3.7	19.2	.0	.6	.6	2.6	31.4
5.7	0.0	5.2	2.1	7.1	9.2	11.1	16.4
5.7	0.0	6.9	1.7	6.1	7.8	11.0	19.5
5.7	2.1	13.8	.2	3.7	3.9	6.1	11.4
5.7	2.1	15.1	.1	2.8	2.9	5.9	10.0
5.7	4.3	19.4	.0	.5	.5	2.4	11.1
11.4	0.0	15.6	.0	2.6	2.6	5.4	16.4
11.4	3.4	17.9	.1	1.7	1.7	2.6	8.7
21.3	0.0	17.3	.0	1.8	1.9	3.8	.8

(a) Water calculation based on carbon monoxide and carbon dioxide.
(b) Water calculation based on oxygen.
(c) Water calculation based on measured mass of water.

TABLE VII CONTINUED
TEST 4
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 120 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Hydrogen	Argon	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen
.7	0.0	8.4	.5	11.4	11.2	5.3	46.5
1.4	0.0	4.3	.7	4.2	4.3	2.2	63.4
1.4	0.0	5.8	.7	4.6	4.5	1.8	61.0
1.4	.5	6.1	.6	6.7	7.2	5.2	54.8
1.4	2.0	1.2	.8	.6	.7	.1	74.1
1.4	2.7	.0	.9	.0	.0	.0	77.1
1.4	3.7	.0	.9	.0	.0	.0	77.9
2.9	0.0	6.8	.7	2.4	1.4	.5	65.5
2.9	0.0	4.9	.7	2.4	1.6	.6	67.8
2.9	1.4	1.0	.8	.4	.3	.0	75.6
2.9	1.4	.6	.8	.1	.1	.5	75.1
2.9	3.7	.0	.9	.0	.0	.0	78.6
5.7	0.0	3.9	.8	.5	.2	.0	70.8
5.7	0.0	3.3	.8	.5	.2	.0	72.7
5.7	2.1	.2	.9	.0	.0	.0	77.2
5.7	2.1	.1	.9	.0	.0	.0	78.1
5.7	4.3	.0	.9	.0	.0	.0	78.7
11.4	0.0	.1	.9	.0	.0	.0	78.1
11.4	3.4	.0	.9	.0	.0	.0	77.7
21.3	0.0	.0	.9	.0	.0	.0	78.1

TABLE VII CONTINUED
TEST 4
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 120 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
.7	0.0	.025	.028	.084	.052	.007	.008
1.4	0.0	.055	.022	.097	.054	.003	.010
1.4	0.0	.025	.028	.118	.066	.004	.010
1.4	.5	.017	.031	.101	.061	.005	.009
1.4	2.0	.110	.009	.085	.040	.001	.012
1.4	2.7	.172	.001	.046	.020	.000	.012
1.4	3.7	.194	.001	.027	.011	.000	.012
2.9	0.0	.036	.025	.121	.065	.005	.011
2.9	0.0	.069	.018	.103	.053	.004	.011
2.9	1.4	.136	.006	.066	.031	.001	.012
2.9	1.4	.121	.005	.083	.037	.000	.012
2.9	3.7	.211	.000	.010	.004	.000	.012
5.7	0.0	.061	.022	.113	.060	.003	.012
5.7	0.0	.080	.017	.098	.051	.002	.011
5.7	2.1	.154	.002	.056	.024	.000	.012
5.7	2.1	.168	.001	.043	.018	.000	.012
5.7	4.3	.215	.000	.008	.003	.000	.012
11.4	0.0	.172	.000	.040	.016	.000	.012
11.4	3.4	.198	.001	.025	.011	.000	.012
21.3	0.0	.191	.000	.028	.012	.000	.012

TABLE VII CONTINUED
TEST 4
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 120 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen	Unburned Fuel
.7	0.0	.071	.119	.091	.509	.007
1.4	0.0	.025	.043	.035	.653	.004
1.4	0.0	.027	.045	.030	.641	.004
1.4	.5	.041	.074	.086	.576	.001
1.4	2.0	.004	.006	.001	.731	.001
1.4	2.7	.000	.000	.000	.747	.001
1.4	3.7	.000	.000	.000	.754	.000
2.9	0.0	.014	.014	.008	.678	.023
2.9	0.0	.014	.016	.009	.698	.005
2.9	1.4	.002	.002	.000	.743	.001
2.9	1.4	.001	.001	.008	.731	.001
2.9	3.7	.000	.000	.000	.758	.004
5.7	0.0	.003	.002	.000	.718	.006
5.7	0.0	.003	.002	.000	.735	.001
5.7	2.1	.000	.000	.000	.750	.001
5.7	2.1	.000	.000	.000	.758	.000
5.7	4.3	.000	.000	.000	.762	.000
11.4	0.0	.000	.000	.000	.754	.006
11.4	3.4	.000	.000	.000	.752	.001
21.3	0.0	.000	.000	.000	.756	.001

TABLE VII CONTINUED
TEST 4
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 120 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
.7	0.0	.025	.028	.083	.052	.007	.008
1.4	0.0	.054	.021	.096	.053	.003	.010
1.4	0.0	.025	.027	.117	.066	.004	.010
1.4	.5	.016	.030	.100	.060	.005	.009
1.4	2.0	.110	.009	.084	.040	.001	.012
1.4	2.7	.172	.001	.046	.020	.000	.012
1.4	3.7	.194	.001	.027	.011	.000	.012
2.9	0.0	.035	.024	.117	.063	.005	.010
2.9	0.0	.067	.017	.101	.052	.004	.011
2.9	1.4	.135	.006	.066	.031	.001	.012
2.9	1.4	.120	.005	.082	.037	.000	.012
2.9	3.7	.211	.000	.010	.004	.000	.012
5.7	0.0	.059	.021	.111	.059	.003	.011
5.7	0.0	.078	.016	.096	.050	.002	.011
5.7	2.1	.154	.002	.056	.024	.000	.012
5.7	2.1	.168	.001	.043	.018	.000	.012
5.7	4.3	.215	.000	.008	.003	.000	.012
11.4	0.0	.172	.000	.040	.016	.000	.012
11.4	3.4	.198	.001	.025	.011	.000	.012
21.3	0.0	.191	.000	.028	.012	.000	.012

TABLE VII CONTINUED
TEST 4
COMBUSTION GAS COMPOSITION
7.5-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 120 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen	Unburned Fuel	Soot
.7	0.0	.071	.118	.090	.506	.007	.006
1.4	0.0	.024	.042	.035	.646	.004	.010
1.4	0.0	.027	.045	.030	.635	.004	.008
1.4	.5	.040	.073	.086	.572	.001	.007
1.4	2.0	.004	.006	.001	.727	.001	.005
1.4	2.7	.000	.000	.000	.746	.001	.001
1.4	3.7	.000	.000	.000	.754	.000	.001
2.9	0.0	.014	.014	.008	.658	.022	.030
2.9	0.0	.014	.016	.009	.685	.005	.019
2.9	1.4	.002	.002	.000	.738	.001	.006
2.9	1.4	.001	.001	.008	.727	.001	.006
2.9	3.7	.000	.000	.000	.758	.004	.001
5.7	0.0	.003	.002	.000	.704	.006	.020
5.7	0.0	.003	.002	.000	.721	.001	.019
5.7	2.1	.000	.000	.000	.750	.001	.000
5.7	2.1	.000	.000	.000	.758	.000	.000
5.7	4.3	.000	.000	.000	.762	.000	.000
11.4	0.0	.000	.000	.000	.752	.006	.002
11.4	3.4	.000	.000	.000	.751	.001	.001
21.3	0.0	.000	.000	.000	.756	.001	.001

TABLE VIII
TEST 5
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 60 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water (a)	Water (b)	Water (c)
.7	0.0	2.2	3.0	4.5	7.5	9.3	19.3
1.4	0.0	.3	3.1	5.6	8.7	11.5	7.9
1.4	0.0	.9	3.1	5.4	8.5	11.0	20.7
1.4	1.8	2.6	2.5	6.0	8.5	9.7	48.9
1.4	3.7	11.4	.6	5.4	6.0	6.0	5.8
2.9	0.0	2.1	3.1	6.3	9.4	9.5	13.5
2.9	0.0	.8	3.0	6.5	9.5	10.5	17.8
2.9	1.8	2.3	2.7	7.9	10.6	11.1	13.7
2.9	3.7	16.2	.1	2.8	2.9	3.4	15.0
2.9	4.6	19.2	.0	1.0	1.0	1.6	10.8
2.9	5.8	20.7	.0	.1	.1	.7	23.1
2.9	7.0	20.8	.0	.0	.0	.4	3.3
5.7	0.0	.3	3.8	8.0	11.8	10.4	28.3
5.7	0.0	.3	3.5	7.4	10.9	11.6	18.4
5.7	2.1	9.7	1.0	5.5	6.5	7.7	9.6
5.7	4.3	19.9	.0	.5	.5	1.3	2.7
5.7	6.4	20.8	.0	.0	.0	.4	.5
5.7	6.4	20.8	.0	.1	.1	.3	.2
11.4	0.0	2.1	3.3	7.5	10.8	12.1	19.5
11.4	3.4	14.0	.6	3.6	4.2	4.8	2.1
11.4	6.7	20.7	.0	.2	.2	.1	1.6
21.3	6.7	20.8	.0	.3	.3	.0	26.0

(a) Water calculation based on carbon monoxide and carbon dioxide.
(b) Water calculation based on oxygen.
(c) Water calculation based on measured mass of water.

TABLE VIII CONTINUED
TEST 5
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 60 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Hydrogen	Argon	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen
.7	0.0	5.7	.5	6.8	8.2	13.6	48.0
1.4	0.0	6.2	.5	7.2	8.5	10.5	49.5
1.4	0.0	6.4	.5	7.5	8.6	9.3	49.9
1.4	1.8	6.2	.6	6.3	7.2	5.2	54.8
1.4	3.7	.6	.9	.3	.1	.1	74.6
2.9	0.0	7.2	.6	5.9	6.2	4.9	54.3
2.9	0.0	7.0	.6	7.1	7.5	5.5	52.5
2.9	1.8	5.1	.7	2.8	2.7	1.3	63.8
2.9	3.7	.0	.9	.0	.0	.1	77.0
2.9	4.6	.0	.9	.0	.0	.0	77.9
2.9	5.8	.0	.9	.0	.0	.0	78.3
2.9	7.0	.0	.9	.0	.0	.0	78.2
5.7	0.0	8.3	.7	4.7	3.8	1.7	57.0
5.7	0.0	8.1	.6	5.5	4.6	2.0	56.9
5.7	2.1	1.9	.9	.9	.7	.1	72.8
5.7	4.3	.0	.9	.0	.0	.0	78.2
5.7	6.4	.0	.9	.0	.0	.0	78.2
5.7	6.4	.0	.9	.0	.0	.0	78.2
11.4	0.0	8.2	.8	1.8	.8	.0	64.6
11.4	3.4	1.0	.9	.2	.2	.0	75.4
11.4	6.7	.0	.9	.0	.0	.0	78.0
21.3	6.7	.0	1.0	.0	.0	.0	77.6

TABLE VIII CONTINUED
TEST 5
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 60 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
.7	0.0	.020	.024	.057	.039	.003	.006
1.4	0.0	.003	.026	.073	.047	.004	.006
1.4	0.0	.007	.022	.061	.039	.003	.006
1.4	1.8	.022	.019	.073	.042	.003	.007
1.4	3.7	.120	.006	.079	.036	.000	.012
2.9	0.0	.021	.027	.087	.053	.005	.008
2.9	0.0	.008	.026	.088	.053	.004	.007
2.9	1.8	.026	.027	.124	.068	.004	.010
2.9	3.7	.175	.001	.041	.018	.000	.012
2.9	4.6	.183	.000	.013	.005	.000	.011
2.9	5.8	.198	.000	.001	.000	.000	.011
2.9	7.0	.183	.000	.000	.000	.000	.010
5.7	0.0	.004	.035	.113	.069	.005	.008
5.7	0.0	.003	.033	.112	.067	.006	.009
5.7	2.1	.103	.009	.080	.039	.001	.011
5.7	4.3	.200	.000	.007	.003	.000	.011
5.7	6.4	.230	.000	.001	.000	.000	.013
5.7	6.4	.230	.000	.001	.000	.000	.013
11.4	0.0	.025	.034	.122	.072	.006	.011
11.4	3.4	.156	.006	.056	.026	.001	.012
11.4	6.7	.229	.000	.003	.001	.000	.013
21.3	6.7	.226	.000	.004	.002	.000	.013

TABLE VIII CONTINUED
TEST 5
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 60 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen	Unburned Fuel
.7	0.0	.031	.064	.172	.387	.196
1.4	0.0	.034	.069	.138	.413	.188
1.4	0.0	.031	.060	.105	.359	.307
1.4	1.8	.028	.053	.063	.420	.270
1.4	3.7	.002	.001	.001	.692	.051
2.9	0.0	.030	.053	.069	.478	.170
2.9	0.0	.035	.062	.074	.450	.193
2.9	1.8	.016	.026	.021	.637	.041
2.9	3.7	.000	.000	.002	.729	.021
2.9	4.6	.000	.000	.000	.650	.138
2.9	5.8	.000	.000	.000	.658	.131
2.9	7.0	.000	.000	.000	.601	.205
5.7	0.0	.024	.033	.024	.515	.169
5.7	0.0	.030	.043	.030	.544	.124
5.7	2.1	.005	.006	.001	.676	.068
5.7	4.3	.000	.000	.000	.688	.090
5.7	6.4	.000	.000	.000	.756	.001
5.7	6.4	.000	.000	.000	.756	.000
11.4	0.0	.011	.008	.001	.667	.044
11.4	3.4	.001	.001	.000	.737	.003
11.4	6.7	.000	.000	.000	.754	.001
21.3	6.7	.000	.000	.000	.736	.019

TABLE VIII CONTINUED
TEST 5
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 60 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
.7	0.0	.020	.024	.057	.039	.003	.006
1.4	0.0	.003	.026	.073	.046	.004	.006
1.4	0.0	.007	.022	.061	.039	.003	.006
1.4	1.8	.022	.019	.072	.042	.003	.007
1.4	3.7	.120	.006	.079	.036	.000	.012
2.9	0.0	.020	.027	.086	.052	.005	.008
2.9	0.0	.008	.026	.087	.052	.004	.007
2.9	1.8	.026	.027	.123	.068	.004	.010
2.9	3.7	.175	.001	.041	.018	.000	.012
2.9	4.6	.183	.000	.013	.005	.000	.011
2.9	5.8	.198	.000	.001	.000	.000	.011
2.9	7.0	.183	.000	.000	.000	.000	.010
5.7	0.0	.004	.034	.111	.067	.005	.008
5.7	0.0	.003	.033	.109	.066	.005	.009
5.7	2.1	.102	.009	.079	.038	.001	.011
5.7	4.3	.200	.000	.007	.003	.000	.011
5.7	6.4	.230	.000	.001	.000	.000	.013
5.7	6.4	.230	.000	.001	.000	.000	.013
11.4	0.0	.024	.033	.119	.070	.006	.011
11.4	3.4	.155	.006	.055	.026	.001	.012
11.4	6.7	.229	.000	.003	.001	.000	.013
21.3	6.7	.226	.000	.004	.002	.000	.013

TABLE VIII CONTINUED
TEST 5
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 30 TO 60 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen	Unburned Fuel	Soot
.7	0.0	.031	.064	.172	.386	.196	.003
1.4	0.0	.034	.068	.138	.410	.187	.005
1.4	0.0	.031	.060	.105	.359	.307	.000
1.4	1.8	.027	.053	.063	.418	.268	.005
1.4	3.7	.002	.001	.001	.691	.051	.001
2.9	0.0	.030	.052	.068	.473	.168	.012
2.9	0.0	.035	.061	.074	.447	.192	.007
2.9	1.8	.016	.026	.021	.631	.040	.010
2.9	3.7	.000	.000	.002	.728	.021	.001
2.9	4.6	.000	.000	.000	.650	.138	.000
2.9	5.8	.000	.000	.000	.658	.131	.000
2.9	7.0	.000	.000	.000	.601	.205	.000
5.7	0.0	.024	.032	.024	.506	.166	.018
5.7	0.0	.029	.042	.030	.532	.121	.022
5.7	2.1	.005	.006	.001	.671	.068	.007
5.7	4.3	.000	.000	.000	.688	.090	.000
5.7	6.4	.000	.000	.000	.756	.001	.000
5.7	6.4	.000	.000	.000	.756	.000	.000
11.4	0.0	.010	.008	.000	.647	.042	.030
11.4	3.4	.001	.001	.000	.733	.003	.005
11.4	6.7	.000	.000	.000	.754	.001	.000
21.3	6.7	.000	.000	.000	.736	.019	.000

TABLE IX
TEST 6
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 40 TO 70 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water (a)	Water (b)	Water (c)
.7	0.0	.3	3.2	4.9	8.1	10.0	7.2
1.4	0.0	.4	3.3	4.9	8.2	10.4	13.2
1.4	0.0	.3	3.4	4.9	8.2	10.5	8.4
1.4	1.8	.7	3.1	4.6	7.7	10.5	22.8
1.4	3.7	6.3	1.5	6.8	8.3	9.3	22.6
2.9	0.0	.3	3.2	5.5	8.7	10.1	9.1
2.9	1.2	.8	2.9	5.7	8.6	10.4	8.6
2.9	2.4	5.1	1.6	7.8	9.4	9.9	10.5
2.9	3.7	13.7	.3	4.3	4.6	4.6	6.3
2.9	3.7	12.8	.3	4.8	5.1	5.1	6.6
2.9	6.1	20.8	.0	.2	.2	.0	8.0
5.7	0.0	.4	3.0	6.8	9.8	12.3	16.5
5.7	0.0	1.0	3.0	6.1	9.0	11.4	19.5
5.7	2.1	.8	2.9	8.0	10.8	12.5	6.2
5.7	4.3	17.1	.0	2.2	2.3	3.1	6.6
5.7	4.3	18.1	.0	1.6	1.7	2.3	7.3
11.4	0.0	1.6	4.0	7.2	11.2	12.0	9.0
11.4	2.1	3.8	2.7	7.3	10.0	11.6	7.2
11.4	4.3	11.4	.8	5.0	5.8	6.6	5.2
21.3	0.0	7.7	2.0	6.1	8.0	9.5	11.7
21.3	4.3	16.2	.2	2.4	2.5	4.4	5.6

(a) Water calculation based on carbon monoxide and carbon dioxide.
(b) Water calculation based on oxygen.
(c) Water calculation based on measured mass of water.

TABLE IX CONTINUED
TEST 6
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 40 TO 70 SECONDS OF THE FIRE

(a) Percent by Volume

Height (meters)	Distance (meters)	Hydrogen	Argon	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen
.7	0.0	5.9	.5	8.2	9.3	15.5	44.2
1.4	0.0	6.1	.5	7.3	9.3	14.5	45.6
1.4	0.0	5.5	.5	6.2	8.3	17.2	45.5
1.4	1.8	6.9	.5	8.0	11.7	11.3	45.5
1.4	3.7	2.5	.8	1.8	2.2	.7	69.1
2.9	0.0	6.5	.5	8.1	10.5	10.3	46.5
2.9	1.2	7.6	.6	8.9	10.6	5.0	49.3
2.9	2.4	3.4	.8	1.3	1.2	.3	69.2
2.9	3.7	.2	.9	.0	.0	.0	75.9
2.9	3.7	.3	.9	.1	.0	.0	75.7
2.9	6.1	.0	.9	.0	.0	.0	77.8
5.7	0.0	7.9	.6	6.7	6.4	2.3	56.0
5.7	0.0	7.6	.6	7.7	8.2	3.4	53.5
5.7	2.1	8.0	.7	3.7	2.8	.7	61.7
5.7	4.3	.0	.9	.0	.0	.0	77.5
5.7	4.3	.0	.9	.0	.0	.0	77.6
11.4	0.0	8.8	.7	2.3	1.0	.3	62.8
11.4	2.1	5.7	.8	1.0	.4	.1	68.1
11.4	4.3	1.1	.9	.2	.1	.0	74.8
21.3	0.0	2.5	.9	.2	.0	.0	72.7
21.3	4.3	.1	.9	.0	.0	.0	77.8

TABLE IX CONTINUED
TEST 6
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 40 TO 70 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
.7	0.0	.003	.029	.069	.047	.004	.006
1.4	0.0	.004	.030	.070	.048	.004	.006
1.4	0.0	.003	.029	.066	.046	.003	.006
1.4	1.8	.008	.031	.070	.048	.005	.007
1.4	3.7	.072	.015	.106	.053	.002	.012
2.9	0.0	.003	.031	.084	.054	.005	.007
2.9	1.2	.008	.026	.080	.050	.005	.007
2.9	2.4	.057	.016	.118	.059	.002	.011
2.9	3.7	.151	.003	.066	.029	.000	.012
2.9	3.7	.142	.003	.073	.032	.000	.012
2.9	6.1	.228	.000	.003	.001	.000	.013
5.7	0.0	.005	.032	.112	.067	.006	.010
5.7	0.0	.012	.030	.098	.060	.006	.009
5.7	2.1	.010	.030	.131	.073	.006	.010
5.7	4.3	.187	.000	.033	.014	.000	.012
5.7	4.3	.197	.000	.025	.010	.000	.012
11.4	0.0	.020	.043	.122	.077	.007	.011
11.4	2.1	.045	.028	.117	.066	.004	.012
11.4	4.3	.128	.008	.077	.036	.001	.012
21.3	0.0	.088	.019	.095	.051	.002	.012
21.3	4.3	.179	.002	.036	.016	.000	.012

TABLE IX CONTINUED
TEST 6
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 40 TO 70 SECONDS OF THE FIRE

(b) Gas Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro-carbons	Nitrogen	Unburned Fuel
.7	0.0	.042	.081	.218	.397	.105
1.4	0.0	.038	.082	.210	.418	.089
1.4	0.0	.031	.069	.234	.393	.119
1.4	1.8	.045	.110	.174	.443	.060
1.4	3.7	.010	.021	.010	.683	.016
2.9	0.0	.045	.098	.158	.451	.065
2.9	1.2	.045	.091	.070	.440	.178
2.9	2.4	.007	.011	.004	.672	.042
2.9	3.7	.000	.000	.000	.733	.007
2.9	3.7	.000	.000	.000	.731	.006
2.9	6.1	.000	.000	.000	.746	.008
5.7	0.0	.040	.065	.038	.588	.037
5.7	0.0	.046	.081	.055	.551	.052
5.7	2.1	.022	.028	.011	.645	.033
5.7	4.3	.000	.000	.000	.745	.007
5.7	4.3	.000	.000	.000	.741	.014
11.4	0.0	.014	.010	.005	.672	.019
11.4	2.1	.006	.004	.002	.700	.016
11.4	4.3	.001	.001	.000	.730	.007
21.3	0.0	.001	.000	.000	.722	.009
21.3	4.3	.000	.000	.000	.750	.005

TABLE IX CONTINUED
TEST 6
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 40 TO 70 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Oxygen	Carbon Monoxide	Carbon Dioxide	Water	Hydrogen	Argon
.7	0.0	.003	.028	.068	.046	.004	.006
1.4	0.0	.004	.030	.070	.048	.004	.006
1.4	0.0	.003	.029	.066	.046	.003	.006
1.4	1.8	.008	.030	.069	.048	.005	.007
1.4	3.7	.071	.015	.105	.053	.002	.011
2.9	0.0	.003	.030	.083	.053	.004	.007
2.9	1.2	.008	.026	.080	.049	.005	.007
2.9	2.4	.056	.015	.117	.058	.002	.011
2.9	3.7	.150	.003	.065	.028	.000	.012
2.9	3.7	.141	.003	.073	.032	.000	.012
2.9	6.1	.228	.000	.003	.001	.000	.013
5.7	0.0	.005	.031	.109	.065	.006	.009
5.7	0.0	.011	.030	.096	.059	.005	.009
5.7	2.1	.010	.029	.127	.071	.006	.010
5.7	4.3	.187	.000	.033	.014	.000	.012
5.7	4.3	.197	.000	.025	.010	.000	.012
11.4	0.0	.019	.041	.117	.074	.007	.011
11.4	2.1	.044	.027	.114	.064	.004	.011
11.4	4.3	.127	.008	.076	.036	.001	.012
21.3	0.0	.086	.019	.093	.050	.002	.012
21.3	4.3	.179	.002	.036	.016	.000	.012

TABLE IX CONTINUED
TEST 6
COMBUSTION GAS COMPOSITION
15.0-METER-DIAMETER JP-4 FUEL FIRE
SAMPLE TAKEN FROM 40 TO 70 SECONDS OF THE FIRE

(c) Total Mass Fraction

Height (meters)	Distance (meters)	Methane	Ethylene Acetylene	Gaseous Hydro- carbons	Nitrogen	Unburned Fuel	Soot
.7	0.0	.041	.080	.216	.392	.104	.012
1.4	0.0	.038	.082	.209	.415	.088	.006
1.4	0.0	.031	.069	.232	.391	.119	.005
1.4	1.8	.044	.109	.172	.438	.059	.010
1.4	3.7	.010	.021	.010	.679	.016	.006
2.9	0.0	.044	.098	.156	.446	.064	.010
2.9	1.2	.045	.090	.069	.438	.177	.005
2.9	2.4	.007	.011	.004	.664	.041	.013
2.9	3.7	.000	.000	.000	.730	.007	.004
2.9	3.7	.000	.000	.000	.729	.006	.002
2.9	6.1	.000	.000	.000	.745	.008	.001
5.7	0.0	.039	.063	.037	.573	.036	.027
5.7	0.0	.045	.079	.054	.540	.051	.020
5.7	2.1	.021	.027	.011	.625	.032	.031
5.7	4.3	.000	.000	.000	.745	.007	.001
5.7	4.3	.000	.000	.000	.740	.014	.001
11.4	0.0	.013	.010	.005	.646	.018	.039
11.4	2.1	.006	.004	.002	.680	.015	.029
11.4	4.3	.001	.001	.000	.725	.007	.008
21.3	0.0	.001	.000	.000	.709	.009	.018
21.3	4.3	.000	.000	.000	.749	.005	.002

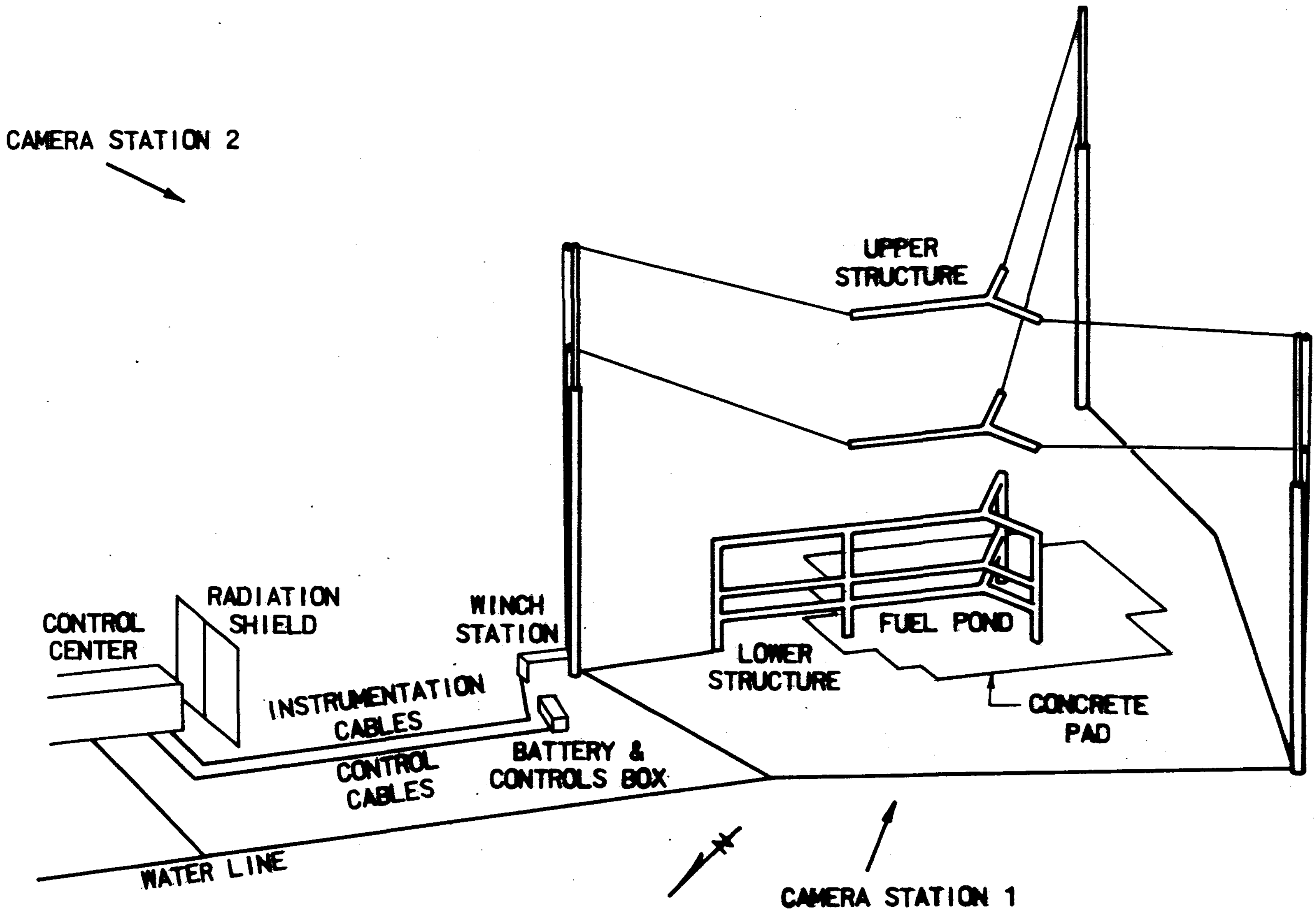


FIGURE 1
TEST SITE

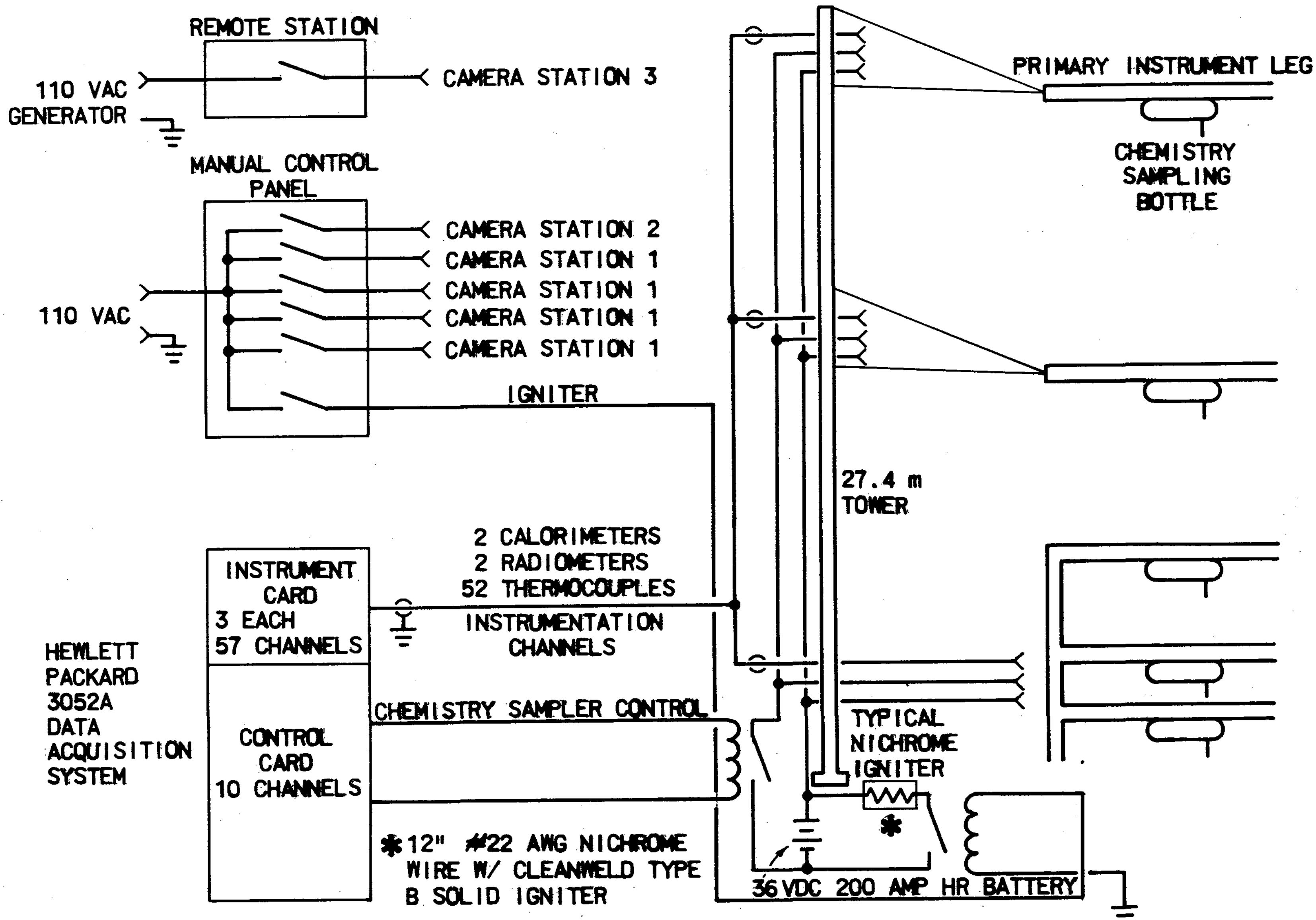


FIGURE 2
INSTRUMENTATION SYSTEM

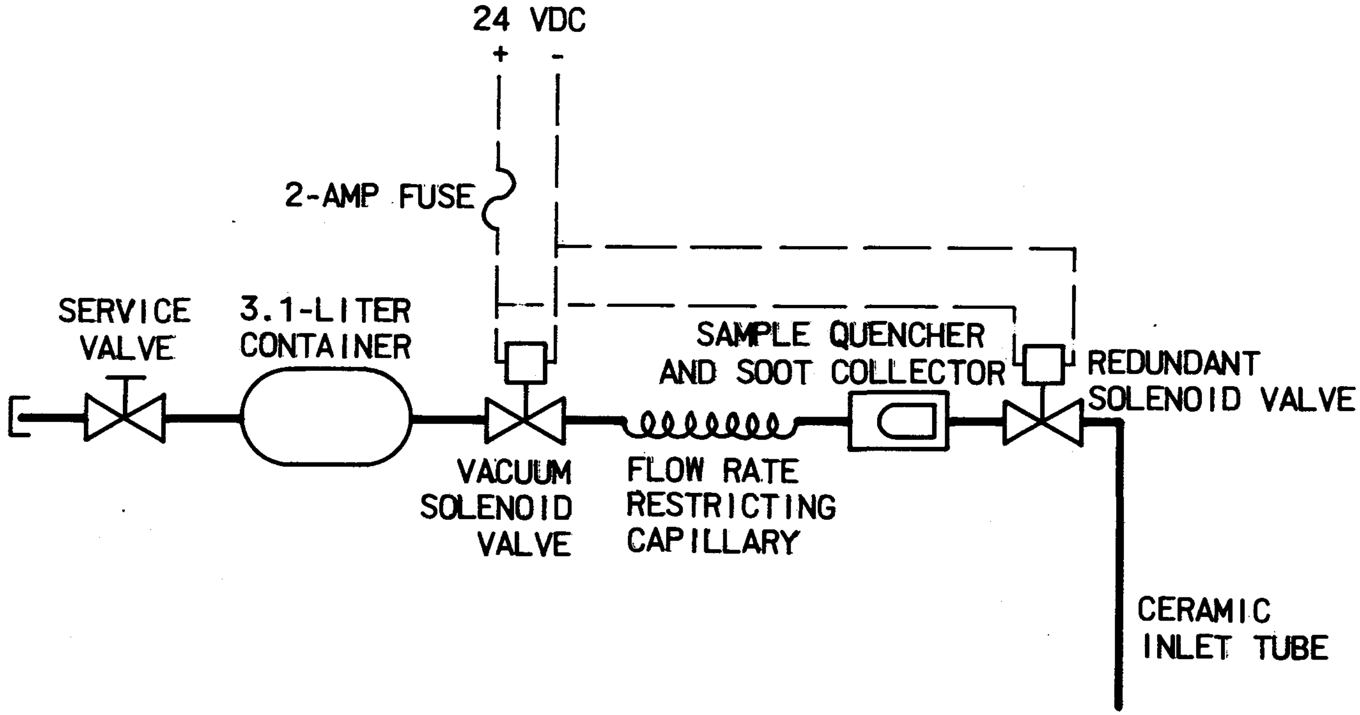
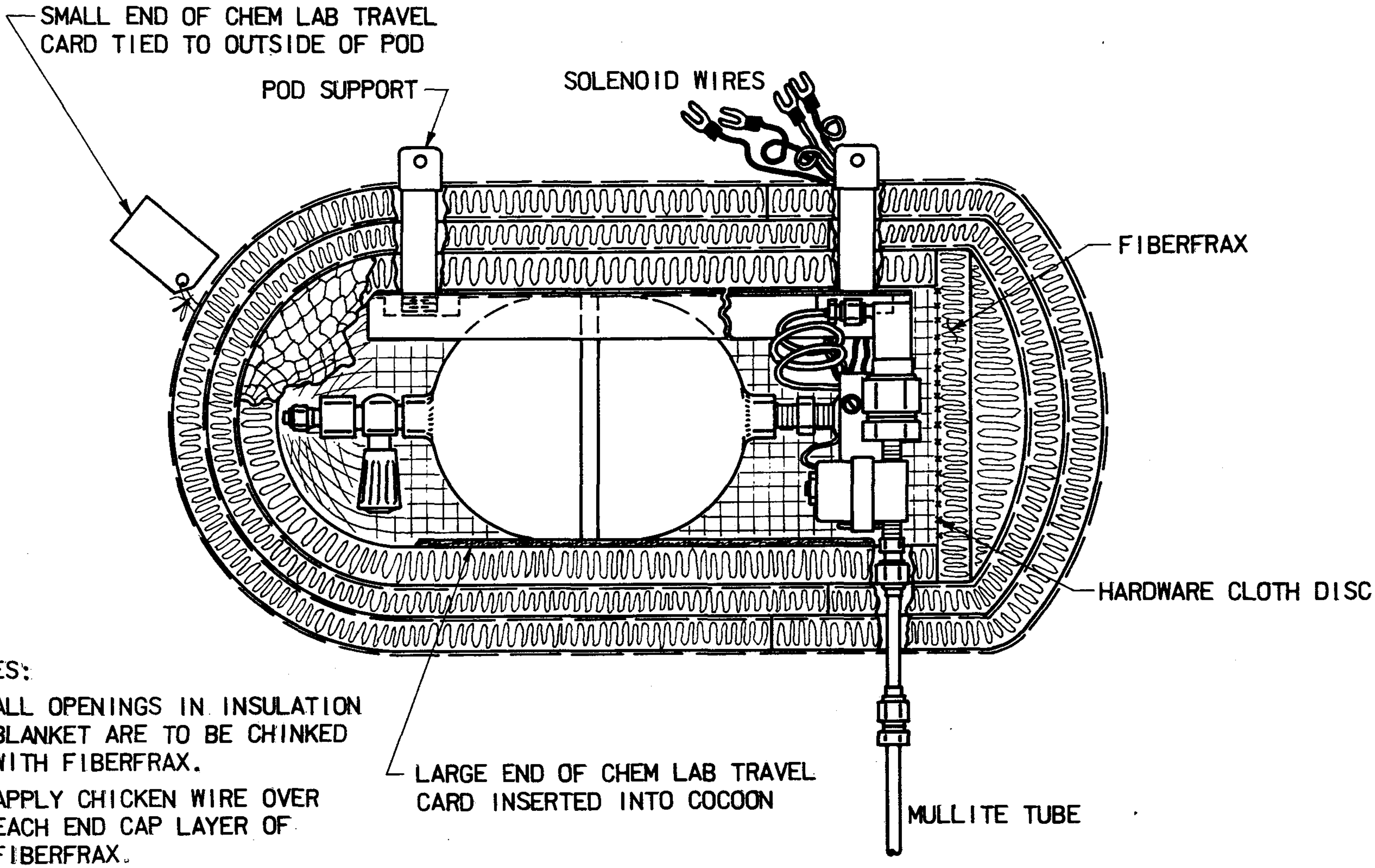


FIGURE 3
CHEMISTRY SAMPLE BOTTLE



NOTES:

1. ALL OPENINGS IN INSULATION BLANKET ARE TO BE CHINKED WITH FIBERFRAX.
2. APPLY CHICKEN WIRE OVER EACH END CAP LAYER OF FIBERFRAX.

FIGURE 4
CHEMISTRY SAMPLER INSULATION AND MOUNTING

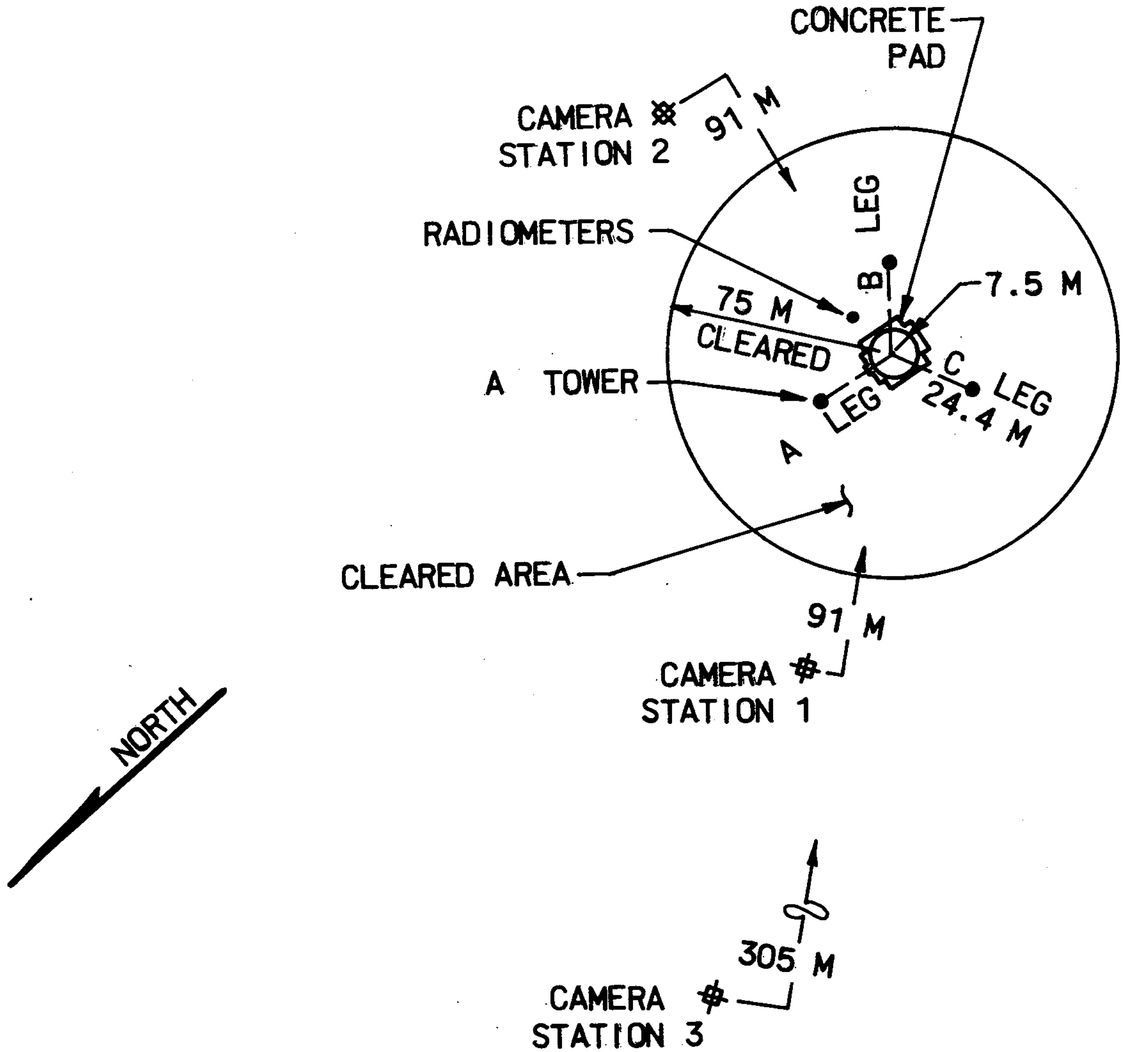
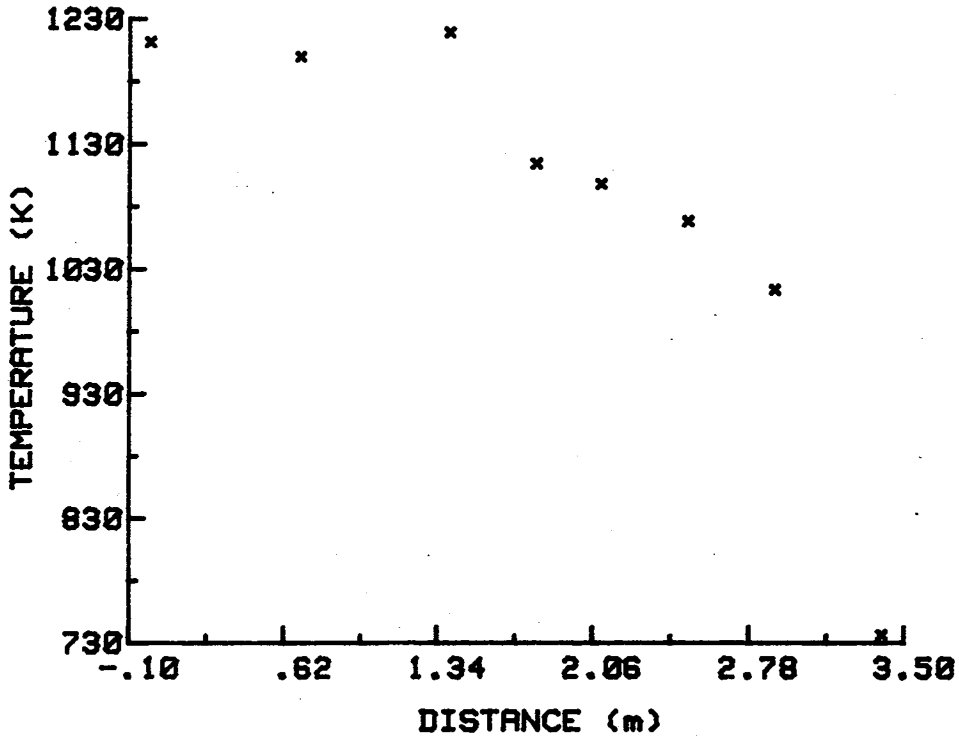


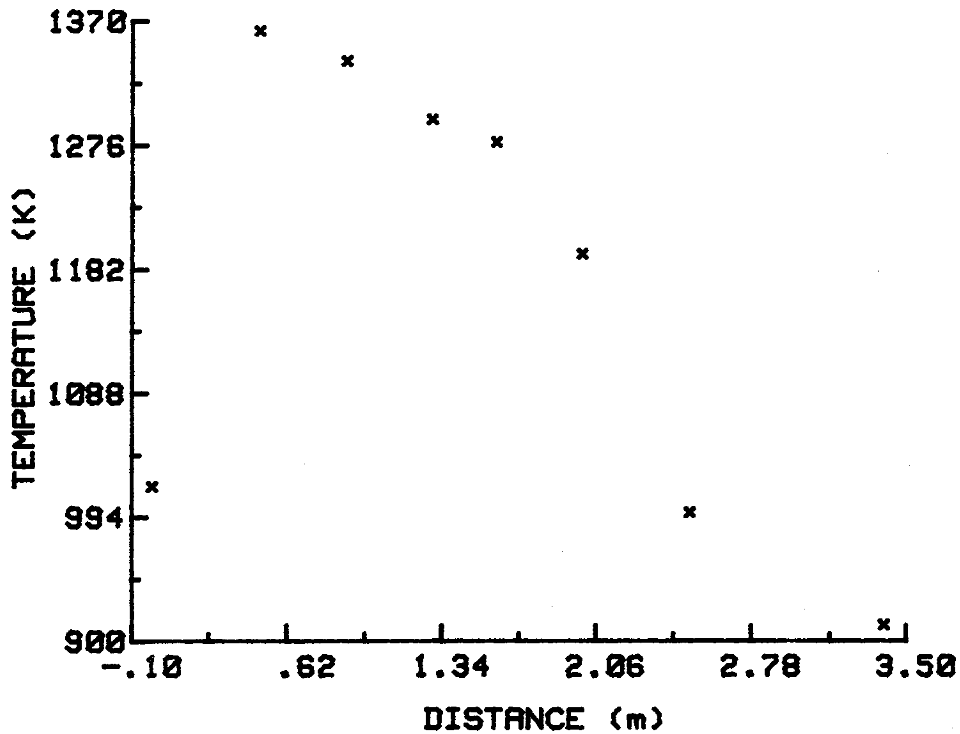
FIGURE 5
TEST SITE INSTRUMENTATION LAYOUT



Average from 10 sec to 40 sec

Figure 6

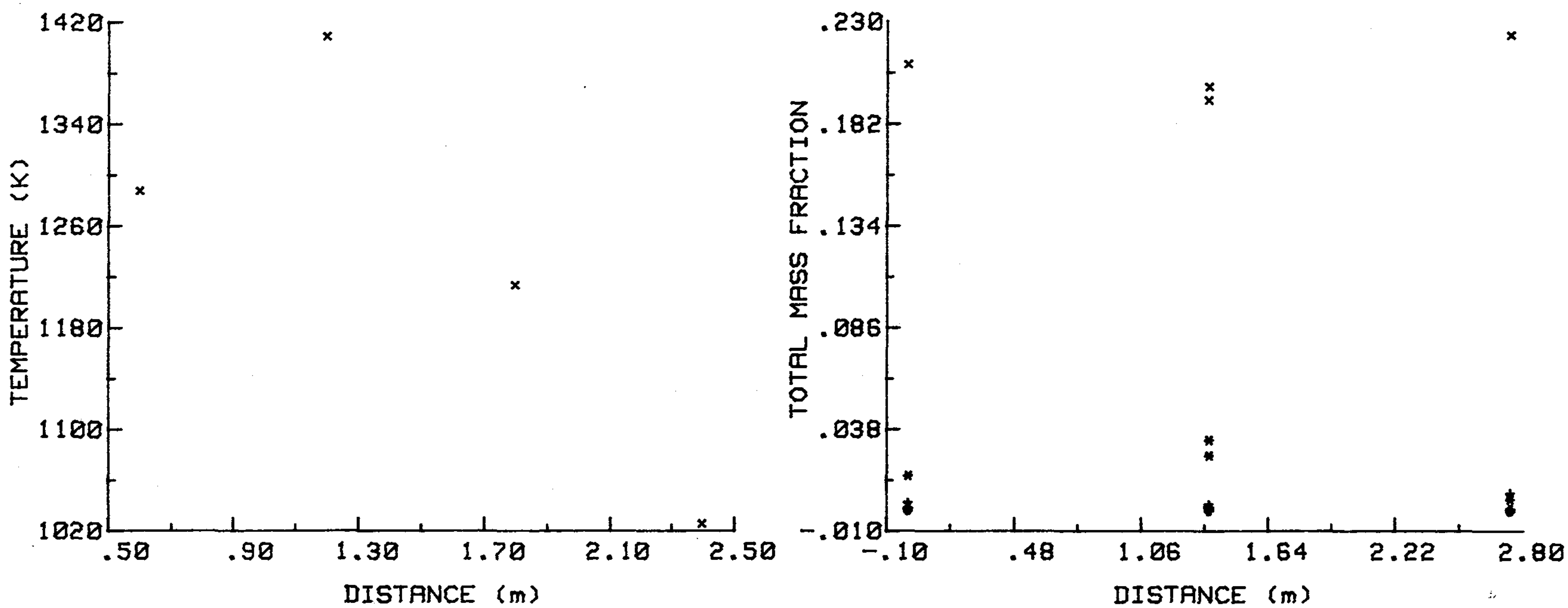
Test 2
7.5 Meter Diameter JP4 Fire
Measurement height=0.7 m



Average from 10 sec to 40 sec

Figure 7

Test 2
7.5 Meter Diameter JP4 Fire
Measurement height=1.4 m



Average from 10 sec to 40 sec

Gas samples taken from 120 sec to 150 sec

x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 8

Test 2
7.5-Meter-Diameter JP-4 Fire
Measurement height=2.9 m

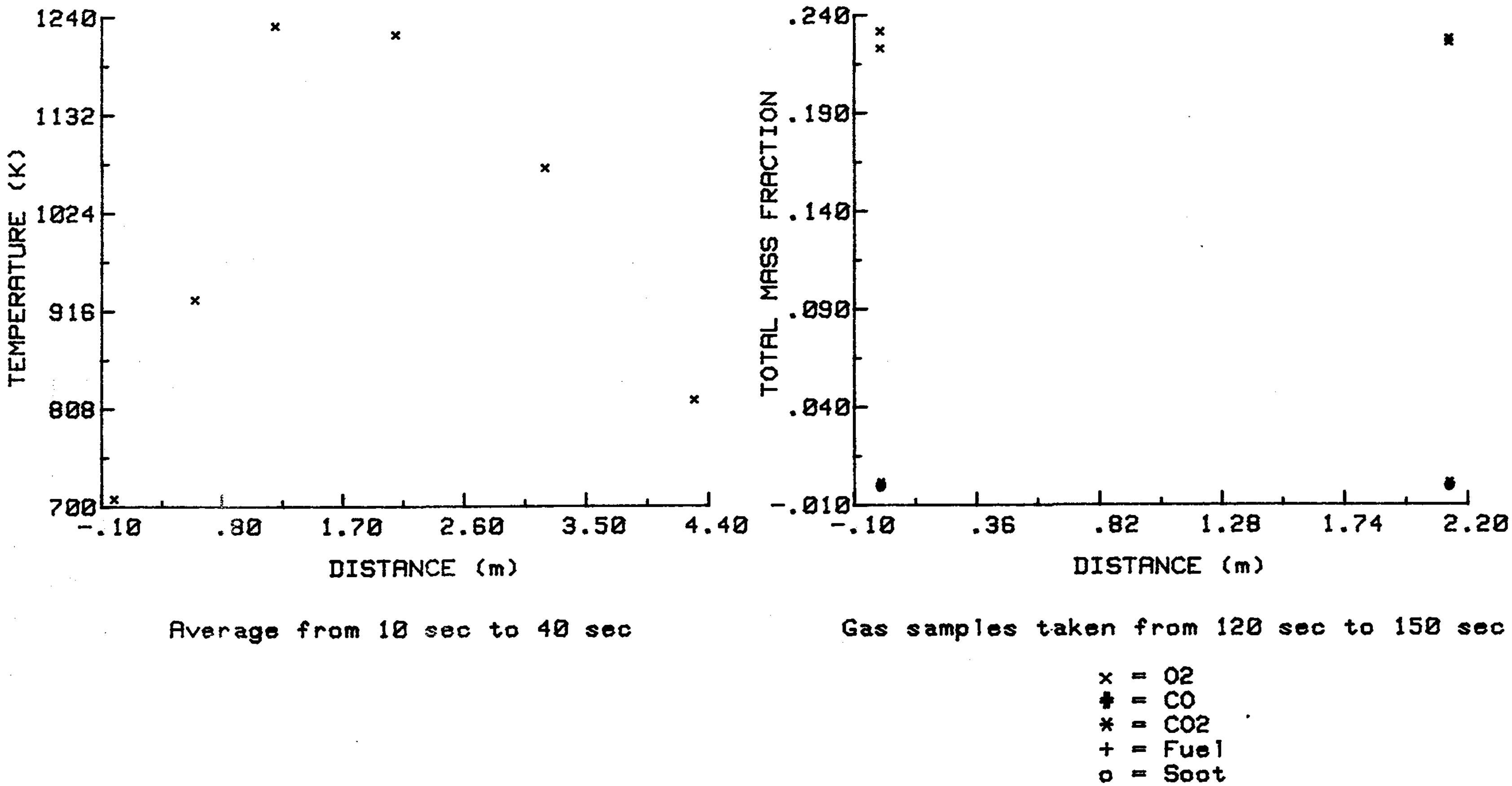
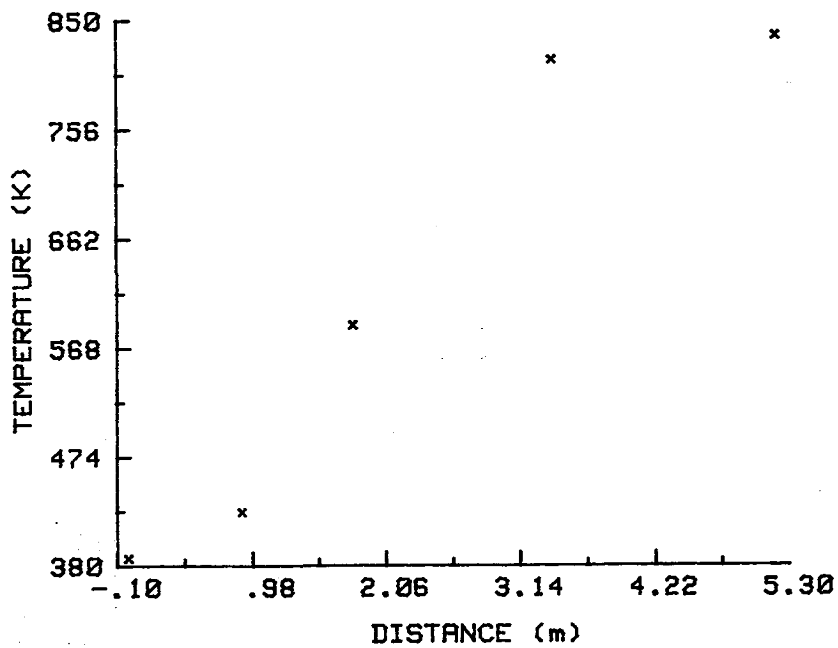
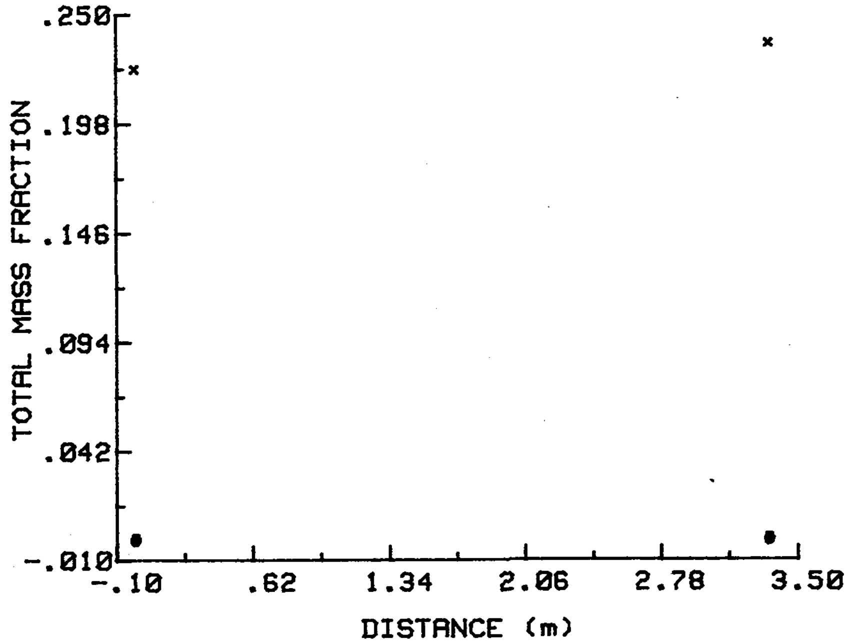


Figure 9

Test 2
7.5-Meter-Diameter JP-4 Fire
Measurement height=5.7 m



Average from 10 sec to 40 sec

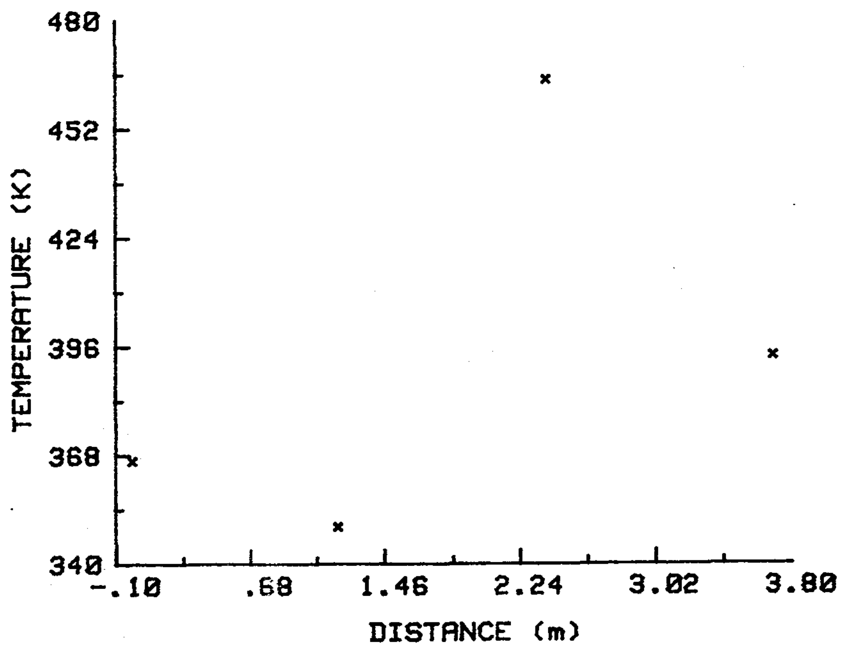


Gas samples taken from 120 sec to 150 sec

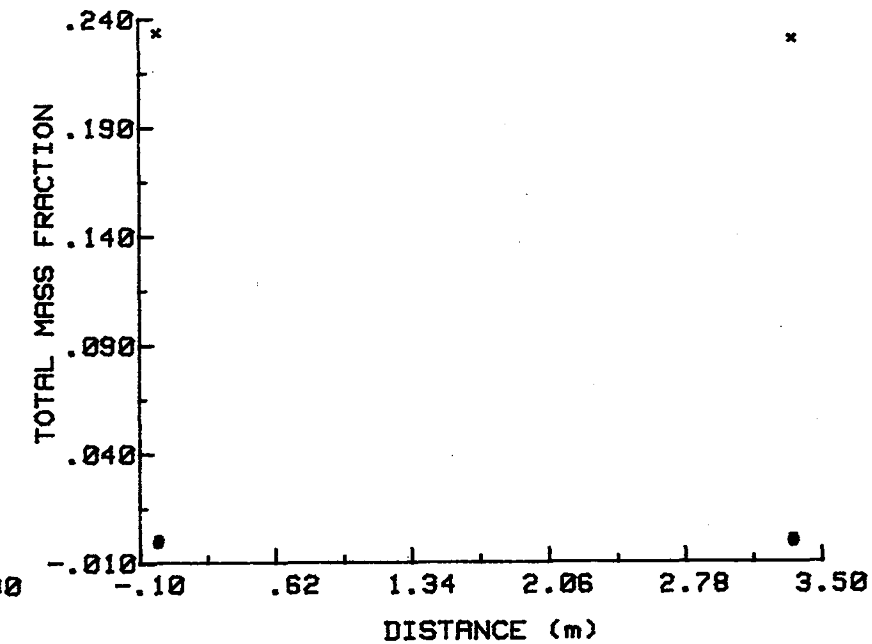
x = O2
● = CO
* = CO2
+ = Fuel
o = Soot

Figure 10

Test 2
7.5-Meter-Diameter JP-4 Fire
Measurement height=11.4 m



Average from 10 sec to 40 sec

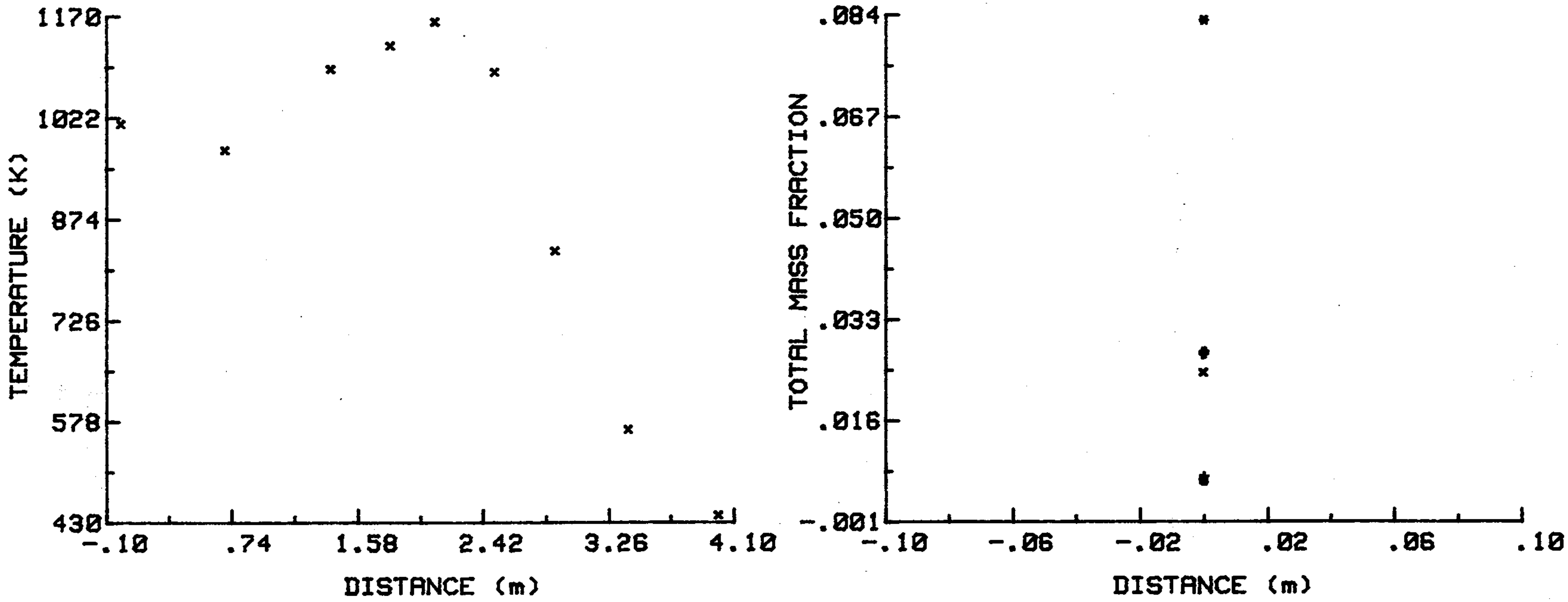


Gas samples taken from 120 sec to 150 sec

x = O2
$\bullet$ = CO
* = CO2
\+ = Fuel
o = Soot

Figure 11

Test 2
7.5-Meter-Diameter JP-4 Fire
Measurement height=21.3 m



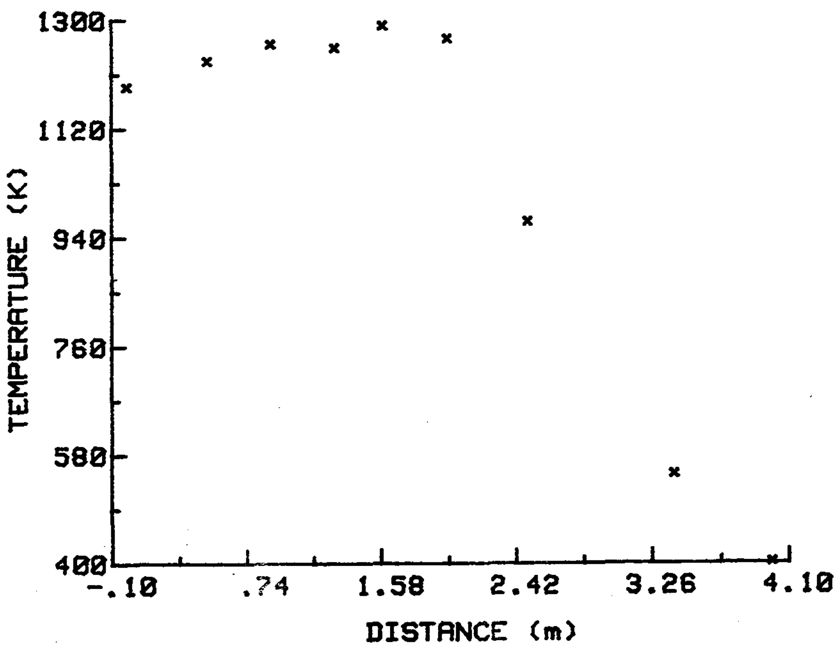
Average from 14 sec to 44 sec

Gas samples taken from 30 sec to 120 sec

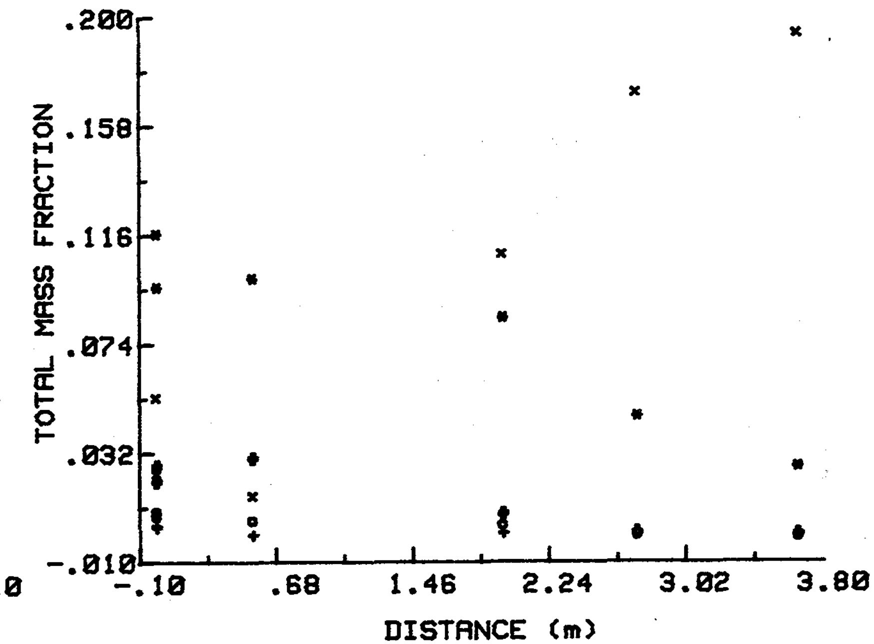
x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 12

Tests 3 and 4
7.5-Meter-Diameter JP-4 Fire
Measurement height=0.7 m



Average from 14 sec to 44 sec

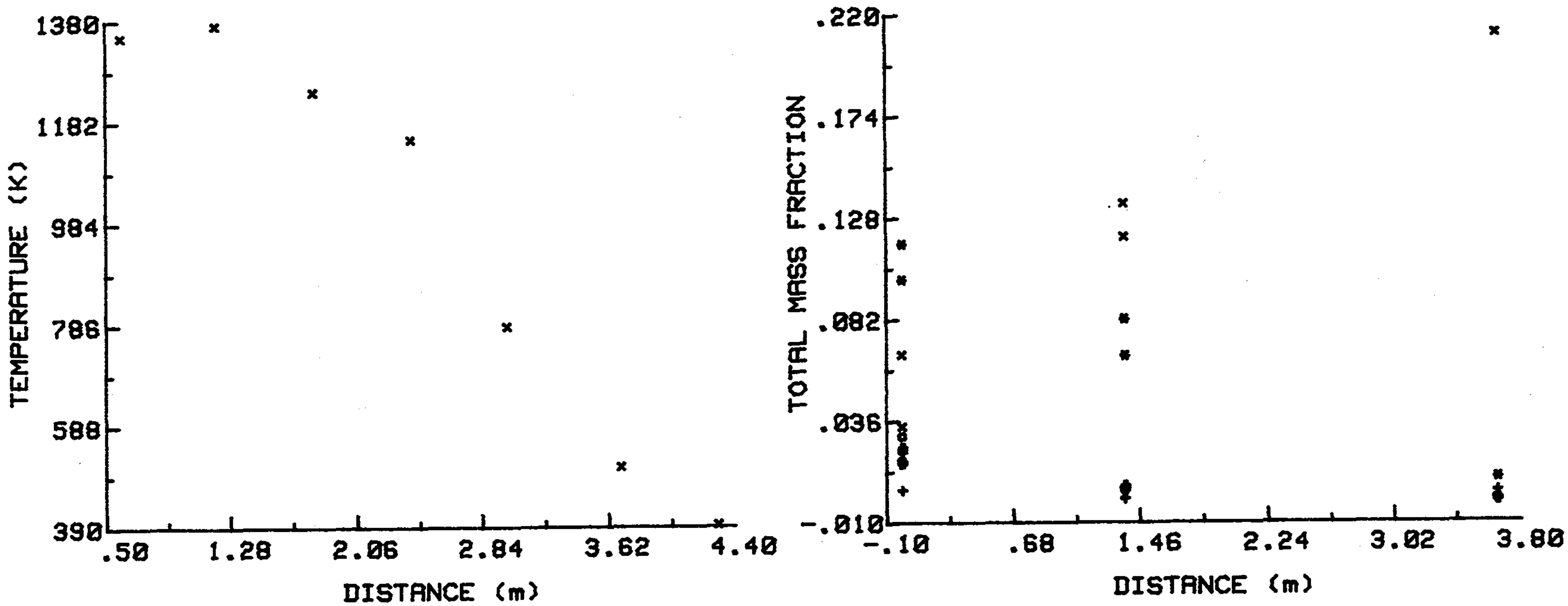


Gas samples taken from 30 sec to 120 sec

x = O2
✱ = CO
* = CO2
+ = Fuel
o = Soot

Figure 13

Tests 3 and 4
7.5-Meter-Diameter JP-4 Fire
Measurement height=1.4 m



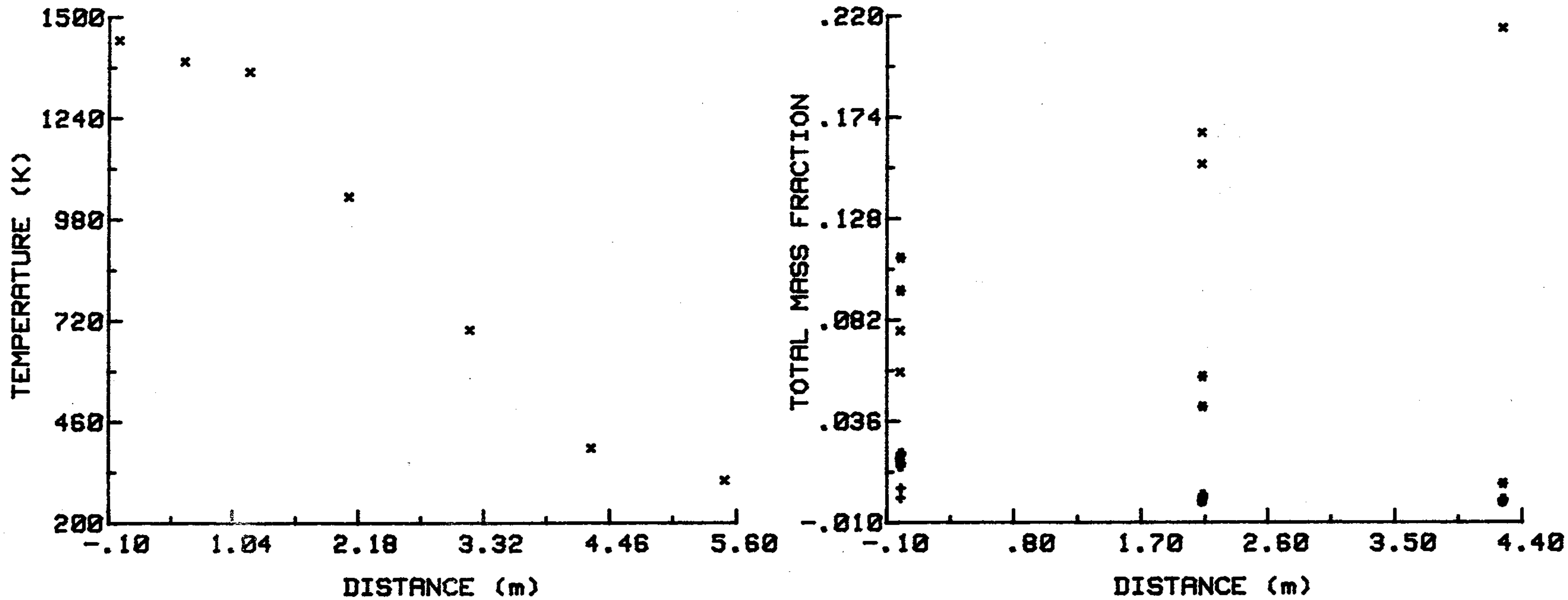
Average from 14 sec to 44 sec

Gas samples taken from 30 sec to 120 sec

x = O2
ɸ = CO
✱ = CO2
\+ = Fuel
o = Soot

Figure 14

Tests 3 and 4
7.5-Meter-Diameter JP-4 Fire
Measurement height=2.9 m



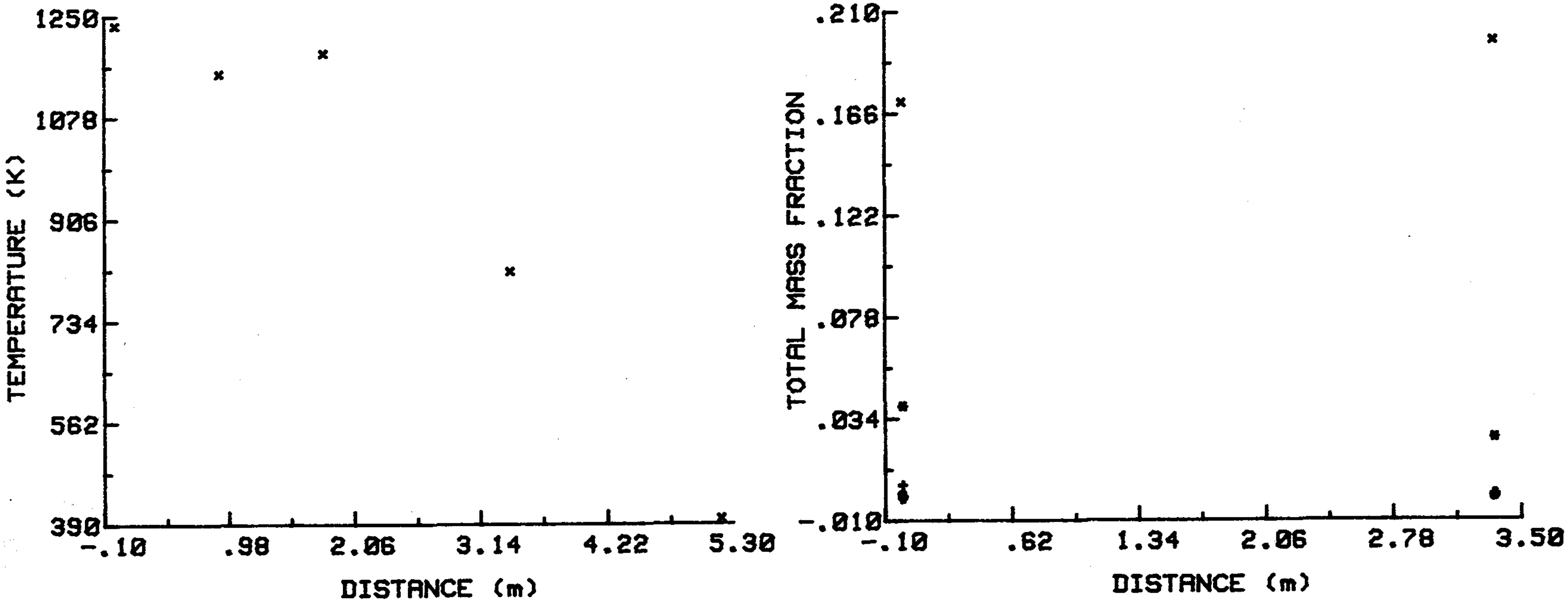
Average from 14 sec to 44 sec

Gas samples taken from 30 sec to 120 sec

x = O2
⧫ = CO
✱ = CO2
\+ = Fuel
o = Soot

Figure 15

Tests 3 and 4
7.5-Meter-Diameter JP-4 Fire
Measurement height=5.7 m



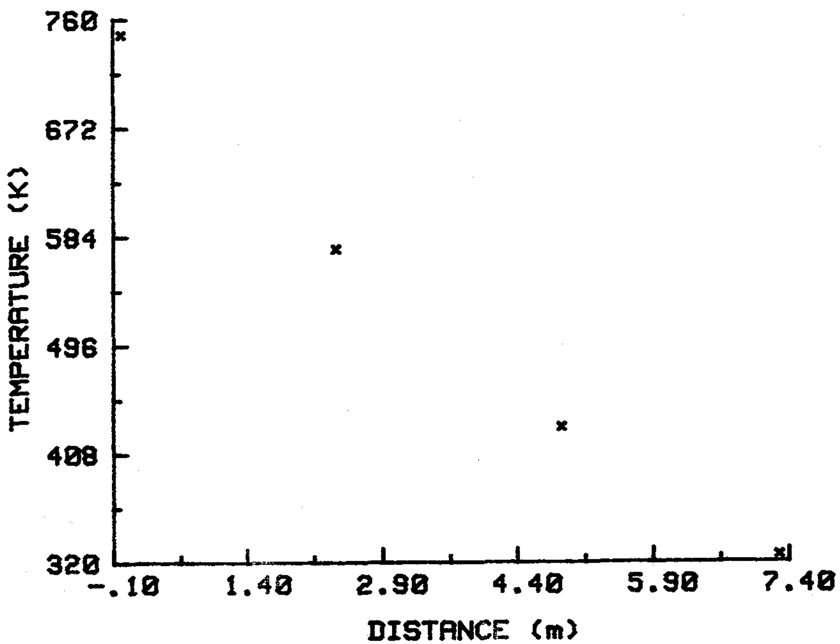
Average from 14 sec to 44 sec

Gas samples taken from 30 sec to 120 sec

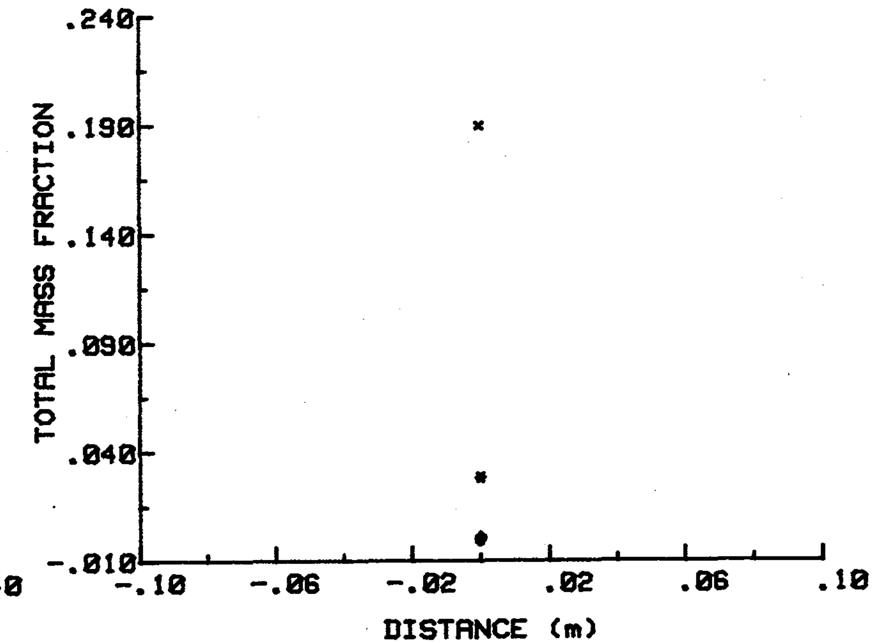
x = O2
ф = CO
* = CO2
+ = Fuel
o = Soot

Figure 16

Tests 3 and 4
7.5-Meter-Diameter JP-4 Fire
Measurement height=11.4 m



Average from 14 sec to 44 sec

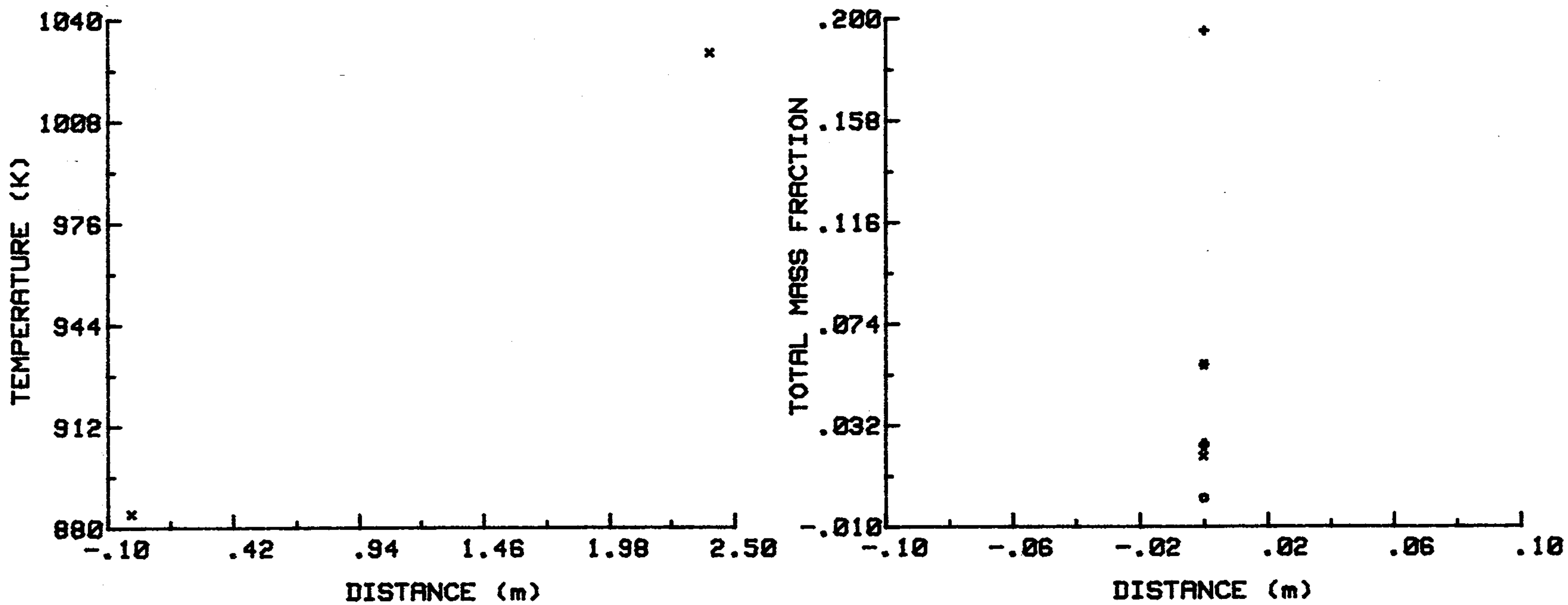


Gas samples taken from 30 sec to 120 sec

x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 17

Tests 3 and 4
7.5-Meter-Diameter JP-4 Fire
Measurement height=21.3 m



Average from 40 sec to 81 sec

Gas samples taken from 30 sec to 60 sec

x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 18

Test 5
15-Meter-Diameter JP-4 Fire
Measurement height=0.7 m

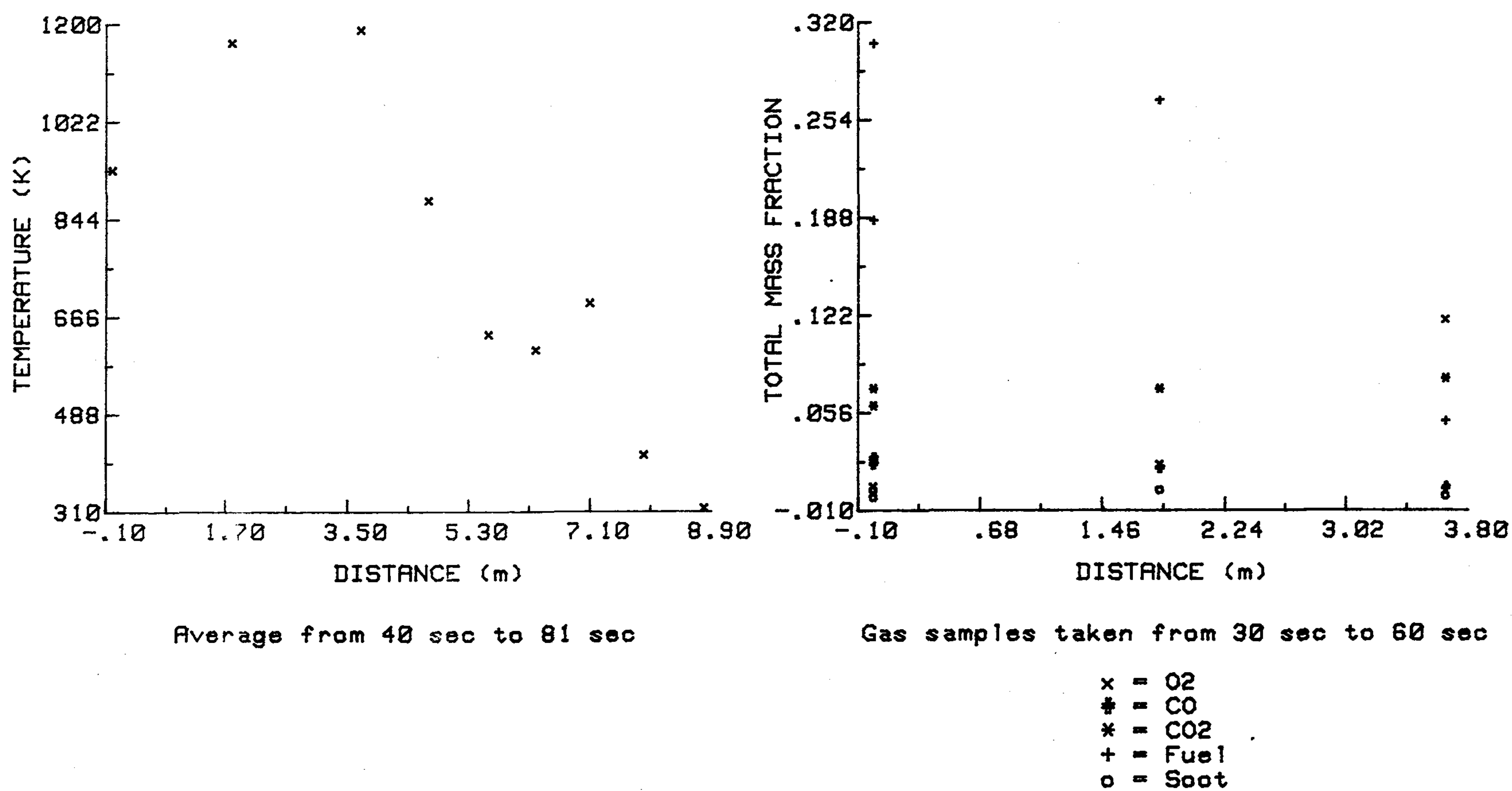
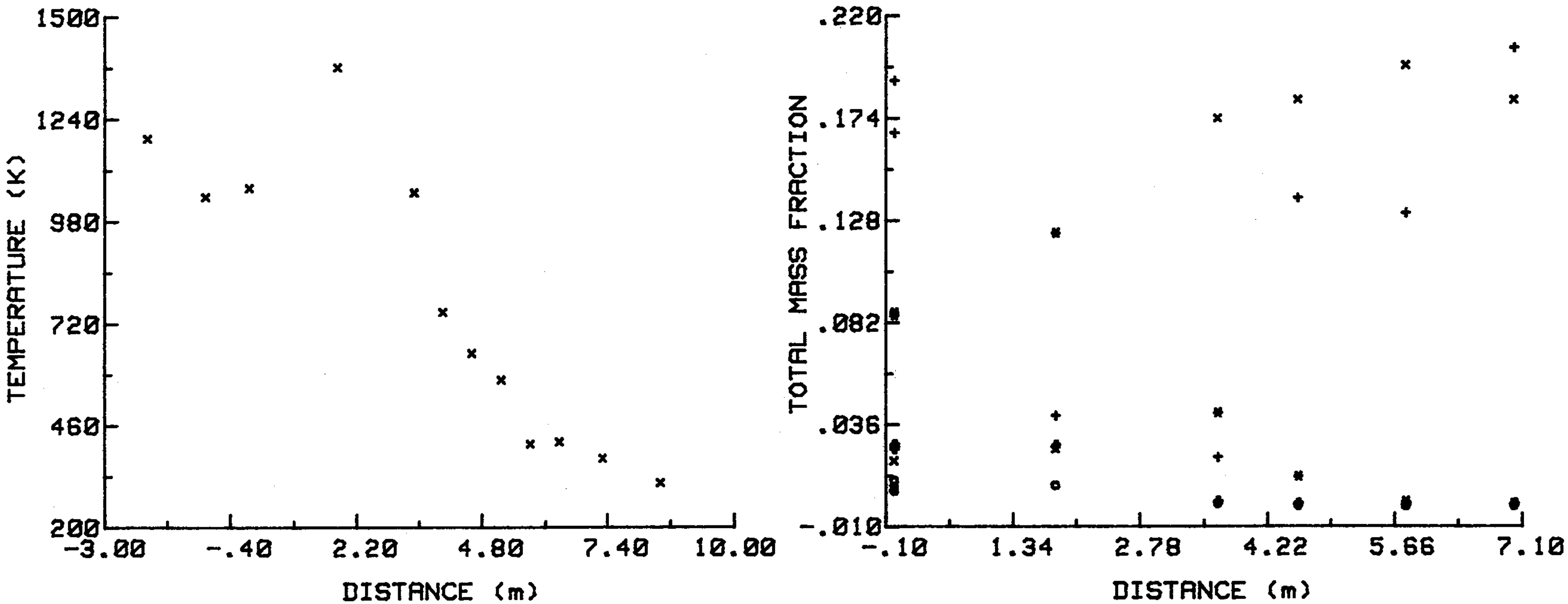


Figure 19

Test 5
15-Meter-Diameter JP-4 Fire
Measurement height=1.4 m



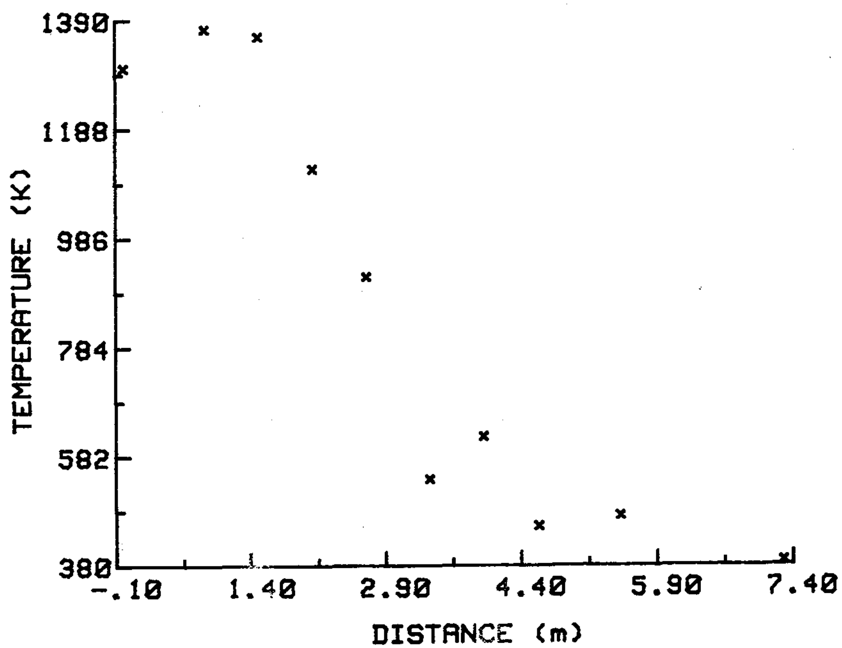
Average from 40 sec to 81 sec

Gas samples taken from 30 sec to 60 sec

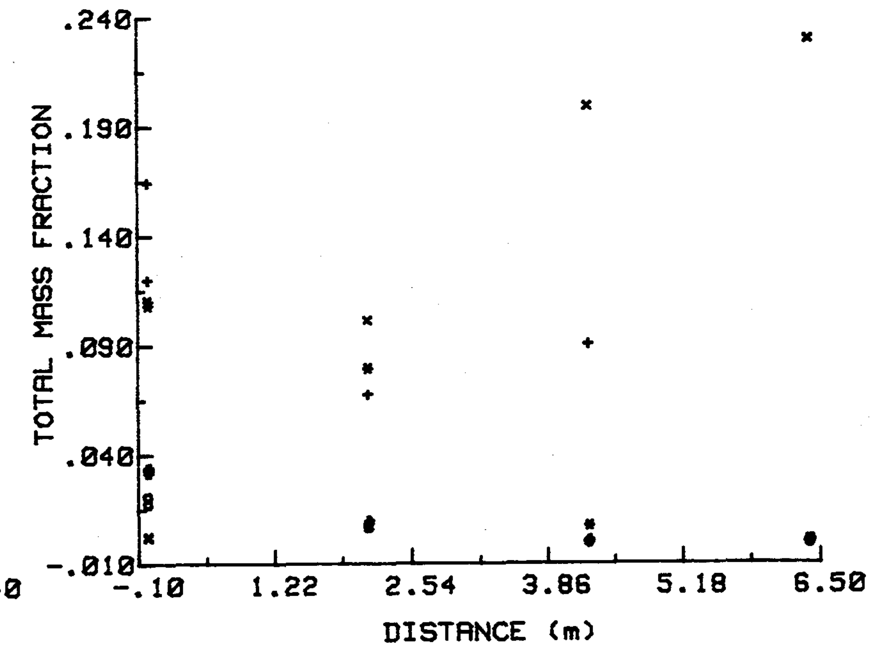
x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 20

Test 5
15-Meter-Diameter JP-4 Fire
Measurement height=2.9 m



Average from 40 sec to 81 sec

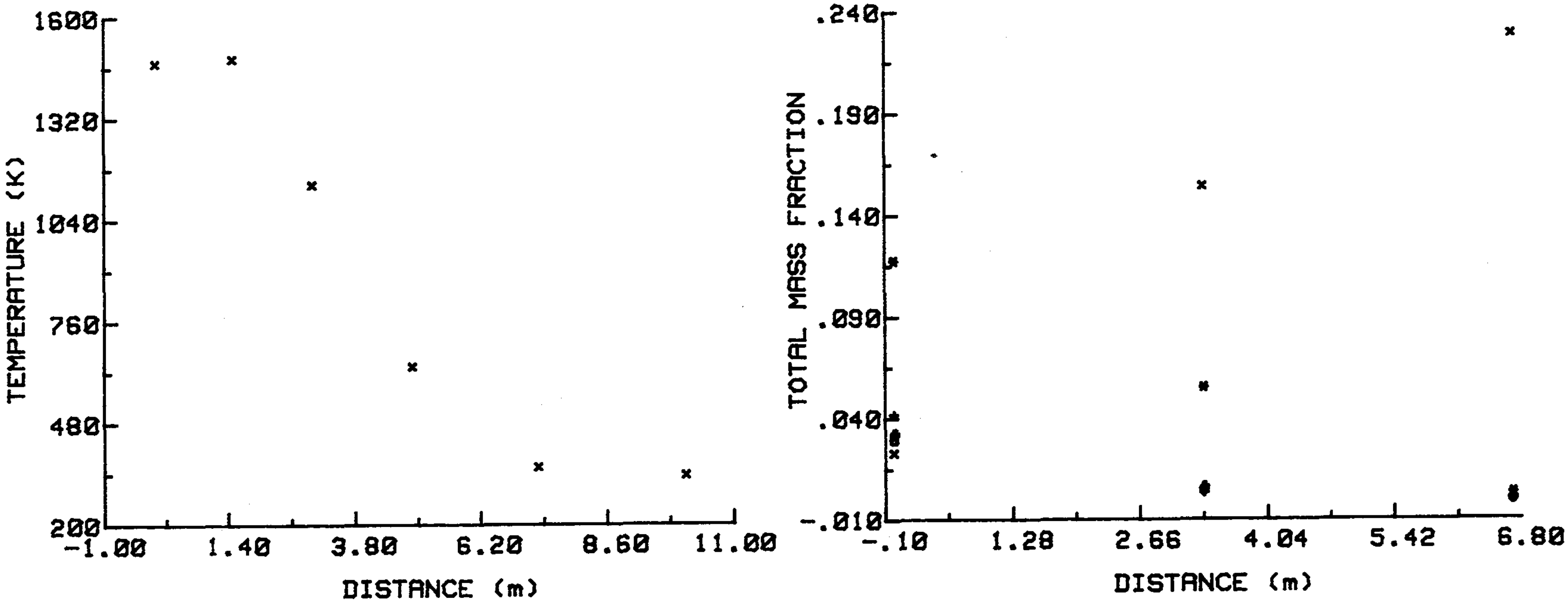


Gas samples taken from 30 sec to 60 sec

x = O2
⁂ = CO
✱ = CO2
\+ = Fuel
o = Soot

Figure 21

Test 5
15-Meter-Diameter JP-4 Fire
Measurement height=5.7 m



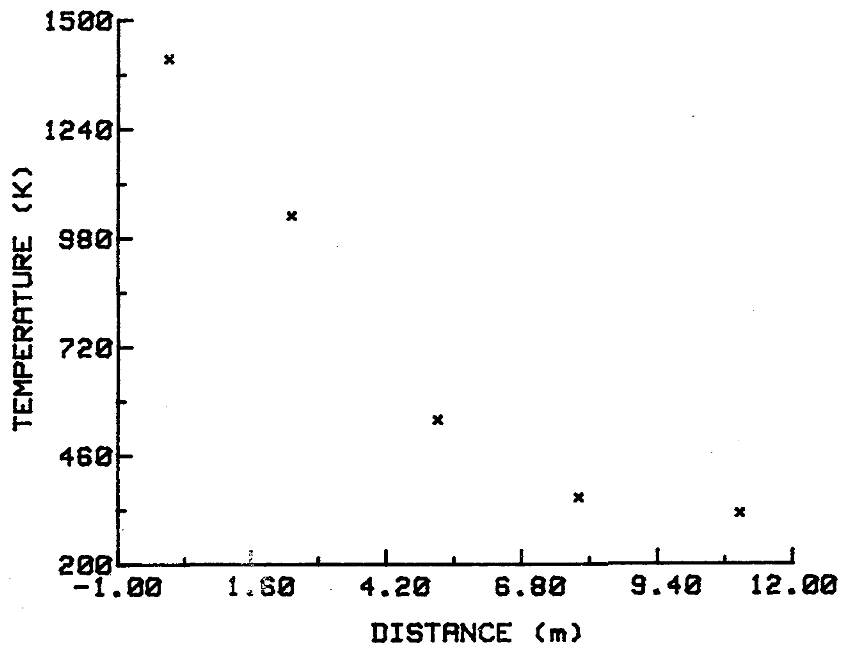
Average from 40 sec to 81 sec

Gas samples taken from 30 sec to 60 sec

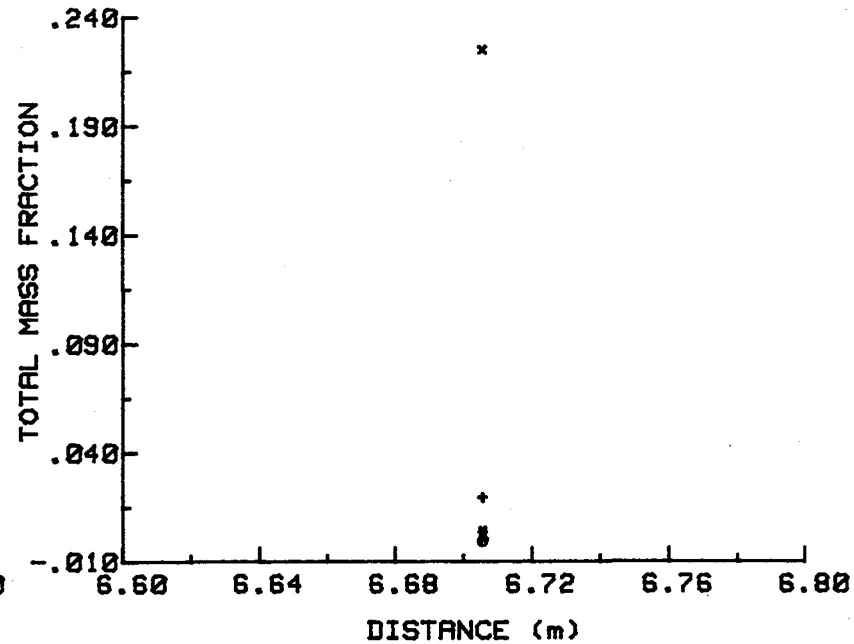
x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 22

Test 5
15-Meter-Diameter JP-4 Fire
Measurement height=11.4 m



Average from 40 sec to 81 sec

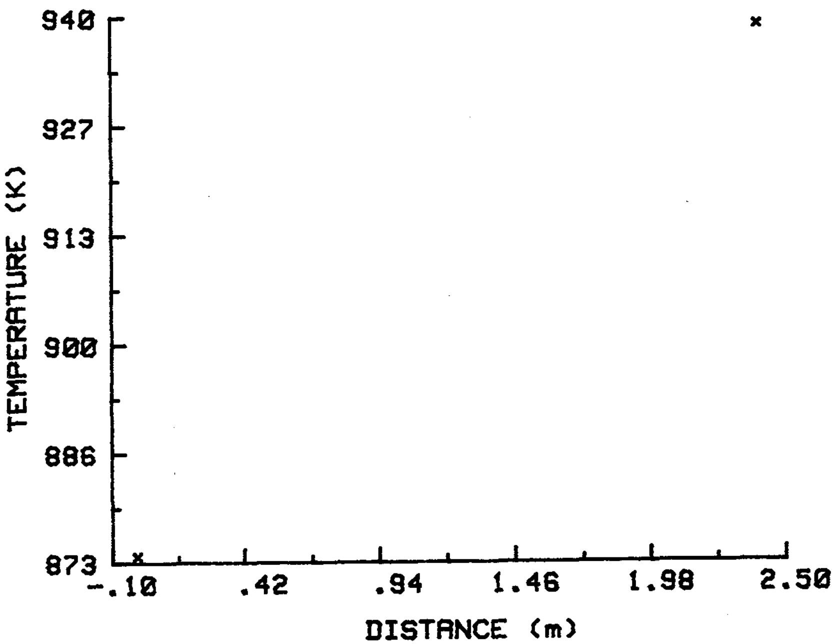


Gas samples taken from 30 sec to 60 sec

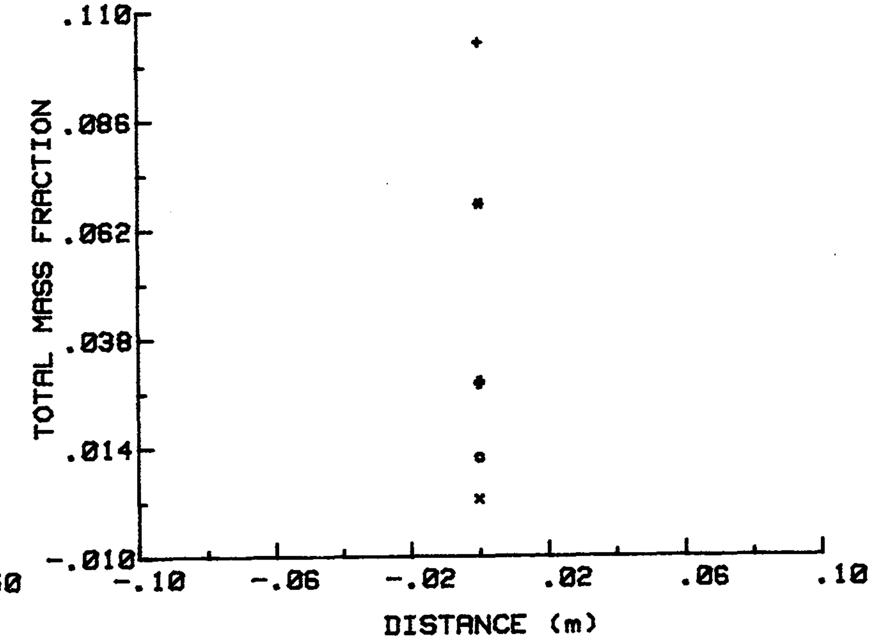
x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 23

Test 5
15-Meter-Diameter JP-4 Fire
Measurement height=21.3 m



Average from 80 sec to 129 sec



Gas samples taken from 40 sec to 70 sec

x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 24

Test 6
15-Meter-Diameter JP-4 Fire
Measurement height=0.7 m

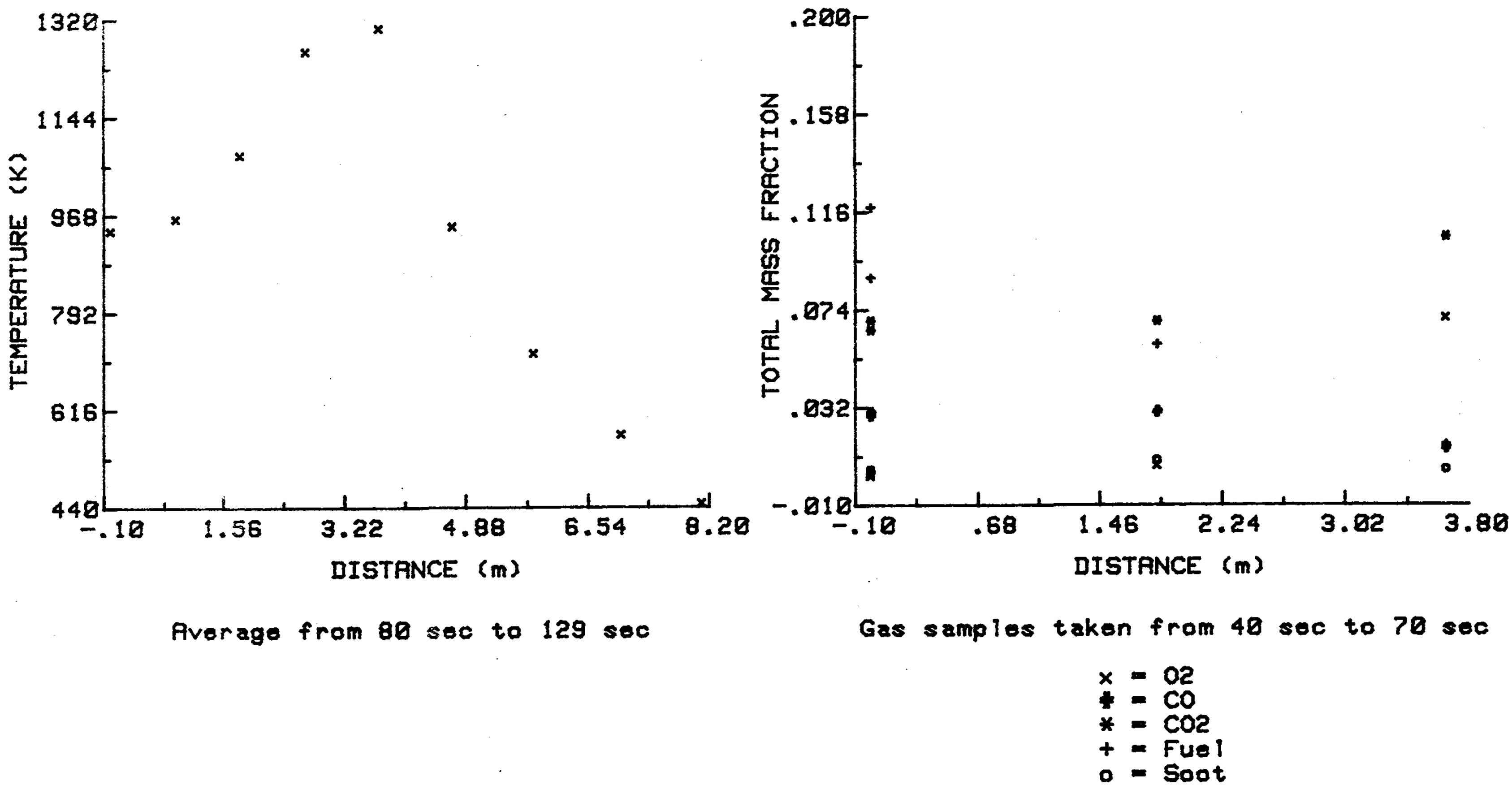


Figure 25

Test 6
15-Meter-Diameter JP-4 Fire
Measurement height=1.4 m

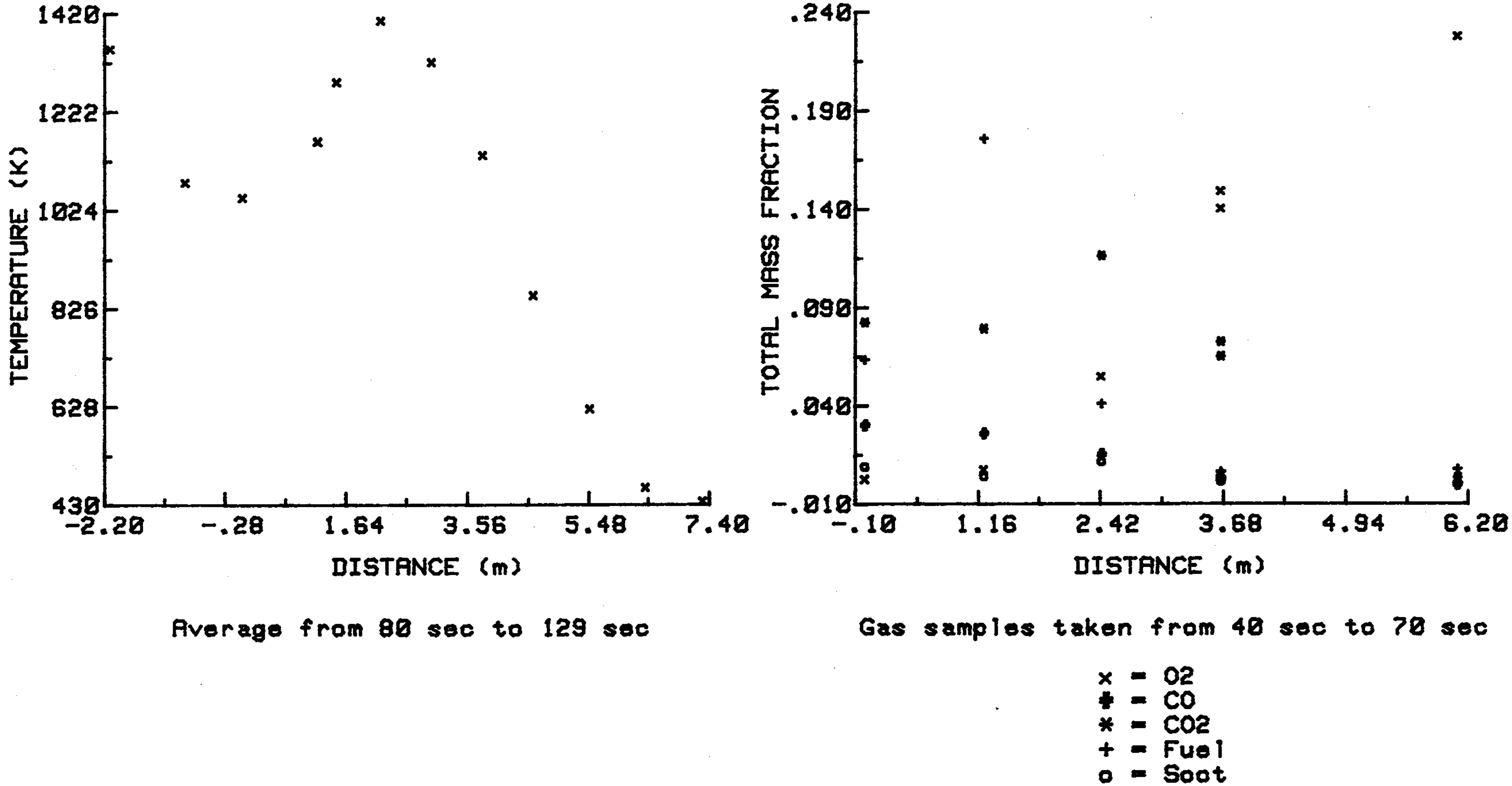


Figure 26

Test 6
15-Meter-Diameter JP-4 Fire
Measurement height=2.9 m

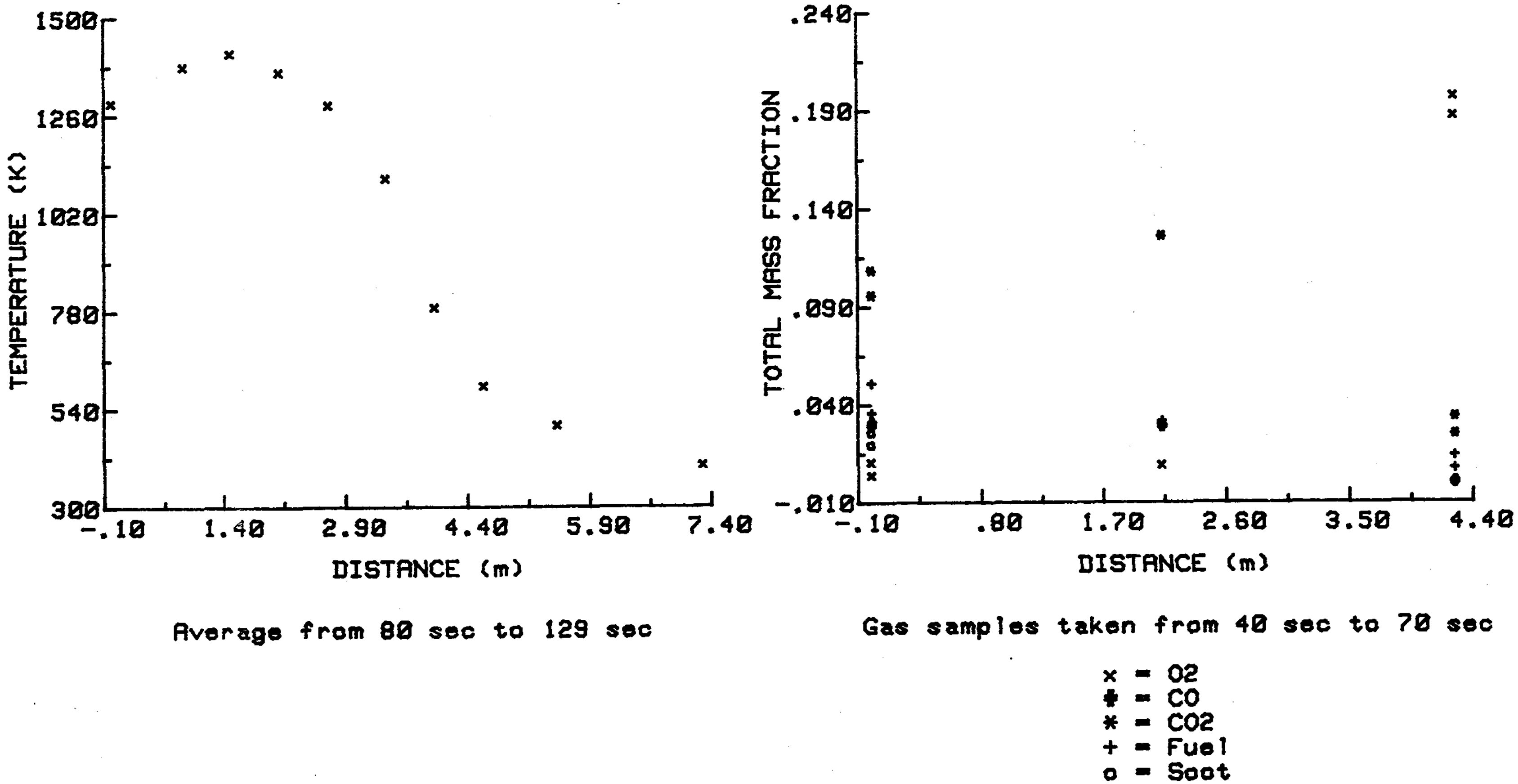


Figure 27

Test 6
15-Meter-Diameter JP-4 Fire
Measurement height=5.7 m

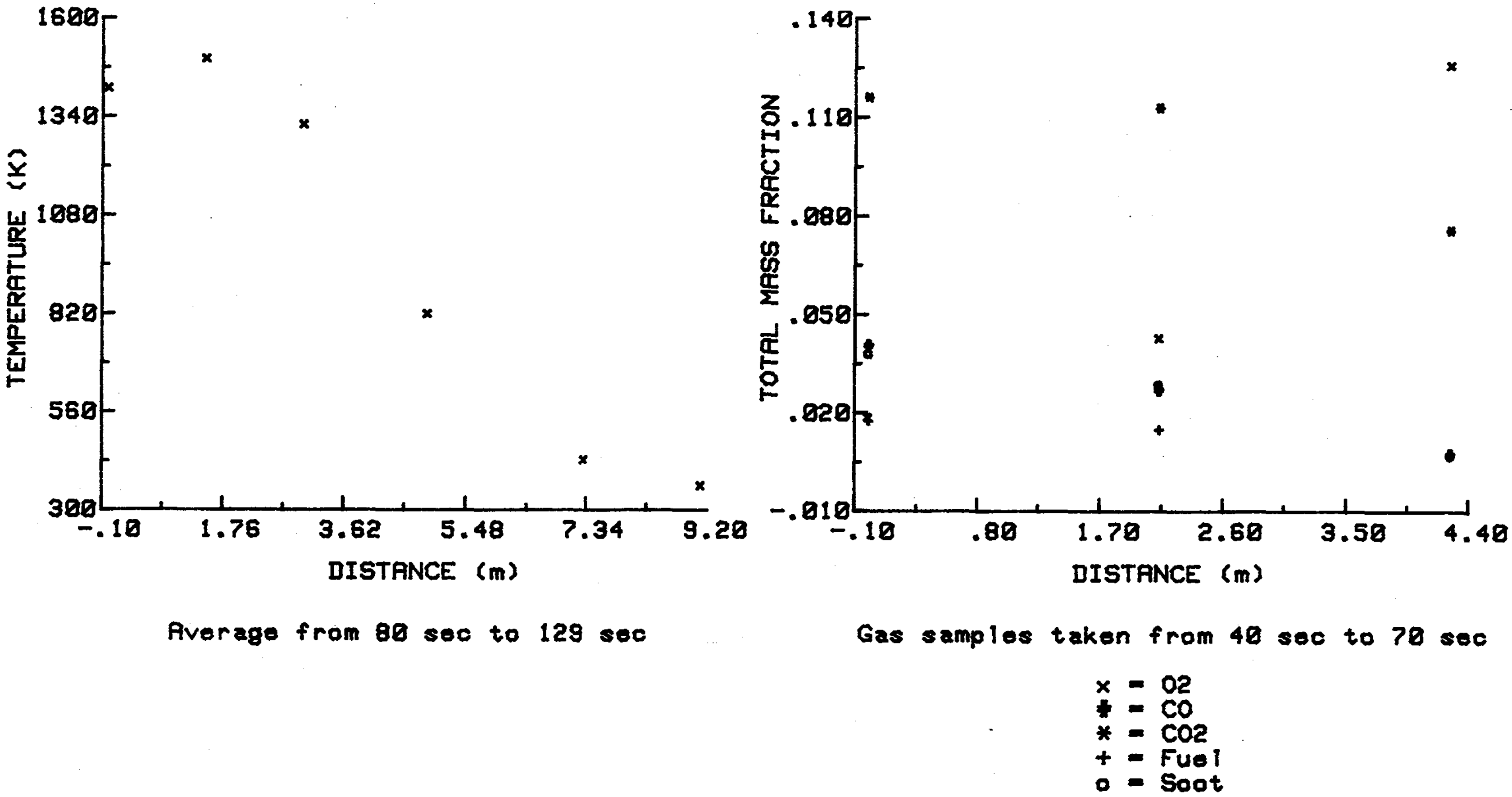
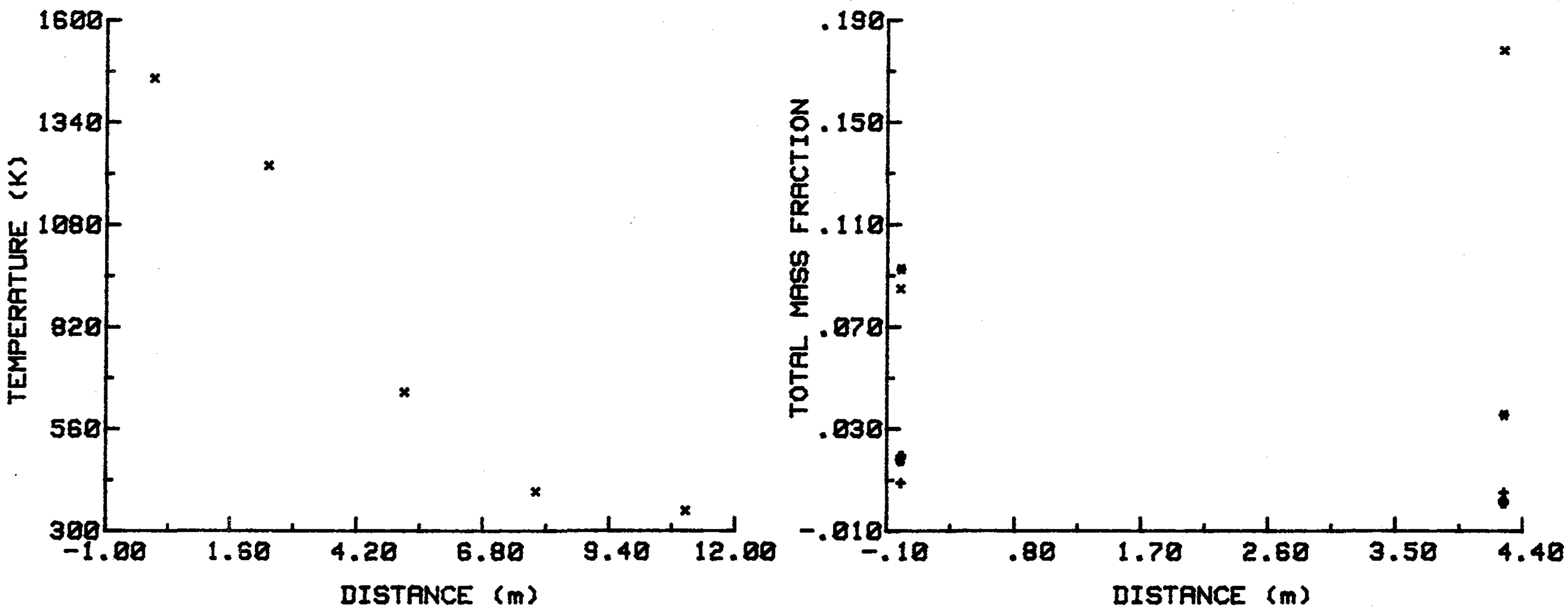


Figure 28

Test 6
15-Meter-Diameter JP-4 Fire
Measurement height=11.4 m



Average from 80 sec to 129 sec

Gas samples taken from 40 sec to 70 sec

x = O2
# = CO
* = CO2
+ = Fuel
o = Soot

Figure 29

Test 6
15-Meter-Diameter JP-4 Fire
Measurement height=21.3 m

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15. Supplementary Notes

16. Abstract

A series of large-scale JP-4 fuel pool fire tests was conducted to refine existing mathematical models of large fires. Seven tests were conducted to make chemical concentration and temperature measurements in 7.5- and 15-meter-diameter pool fires. Measurements were made at heights of 0.7, 1.4, 2.9, 5.7, 11.4, and 21.3 meters above the fires. Temperatures were measured at up to 50 locations each second during the fires. Chemistry samples were taken at up to 23 locations within the fires and analyzed for combustion chemistry and soot concentration. Temperature and combustion chemistry profiles obtained during two 7.5-meter-diameter and two 15-meter-diameter fires are included in this report.

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Soot plume	Combustion temperatures	
Combustion data	Combustion photography	

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